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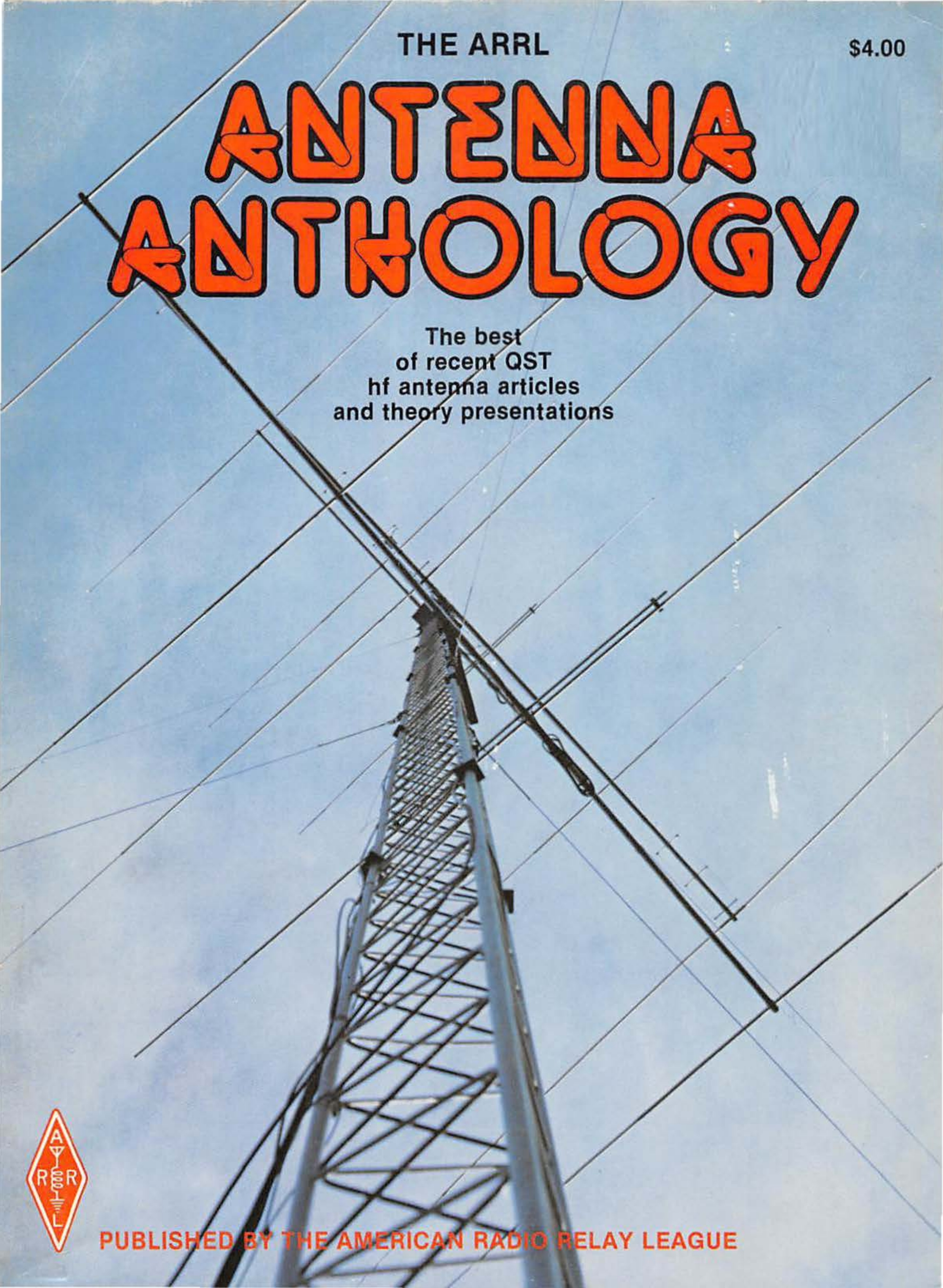

PUBLISHED BY THE AMERICAN RADIO RELAY LEAGUE

The ARRL Antenna Anthology

Edited by
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American Radio Relay League, Inc.
Newington, CT 06111

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Printed in USA

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Library of Congress Catalog Card Number: 78-71955

$4.00 in USA
$4.50 elsewhere

Foreword

What type of amateur antenna best suits your needs? Does the available space on your property permit the installation of an effective DX antenna? Is there a compromise antenna system that will provide acceptable results over short and long distances while being reasonable in price and modest in complexity? No doubt you have come to grips with these matters repeatedly since obtaining your amateur license. So, where does one turn to find the answers to these sometimes perplexing questions? What one pre-eminent source might one consult among all of the antenna booklets published for amateurs? Why, *QST*, naturally!

This anthology contains what the ARRL hq. staff considers the best of the *QST* antenna articles and theory presentations in recent years. The contributions of numerous amateur authors and designers are contained in this volume for your convenience. This publication was developed not only to serve as a compilation of good articles, but to reach those amateurs who do not have access to past issues of the League's official monthly journal, *QST*.

The editors of this booklet have attempted to select the types of antennas that have greatest appeal to those who like to construct their own radiators, and for the many amateurs who can't justify the expense of purchasing commercial counterparts. A book of this type contains something for everyone who enjoys building and experimenting with antennas. But, if you aren't a builder you will still enjoy the hours of interesting reading provided by these works.

We wish to extend our gratitude to those *QST* authors whose articles have been selected for publication in this volume. Their enthusiasm, ability and generosity typifies clearly what Amateur Radio is all about. Should you have some original antenna ideas of proven performance, send an article to the ARRL, describing your work. Not only may your story be published in *QST* — it might appear in a future edition of this book.

Richard L. Baldwin, W1RU
General Manager

Contents

1 Vertical Antennas
Page 7

2 Yagi Antennas
Page 41

3 Quad Antennas
Page 53

4 Miscellaneous Antenna Types
Page 76

5 Antenna Theory and Test Methods
Page 100

Index
Page 150

Chapter 1

Vertical Antennas

One of the most practical antennas for use where limited space exists is the vertical. This type of antenna is particularly useful to amateurs who live in dense urban areas where city lots are traditionally small. The same general restriction prevails for those who dwell in apartment buildings. In such locations it is often easier to go "up" with an antenna than to erect one horizontally. But the virtues of vertical antennas extend beyond the foregoing considerations: "Verticals," as they often are called, are relatively inexpensive, easy to erect and are capable of performing well for local (stateside) and DX work. A vertical antenna exhibits a low angle of radiation when worked against a good ground system. This makes it an effective DX type of antenna.

This chapter contains reprints of some popular vertical-antenna systems that have appeared in *QST* during recent years. For the most part, the presentations contained herein have been "lifted" in their entirety, thus making it unnecessary for the reader to research the original articles for additional information.

A Two-Band Vertical for the Novice

Build this inexpensive Novice antenna. It is easy to construct and is made from readily available materials.

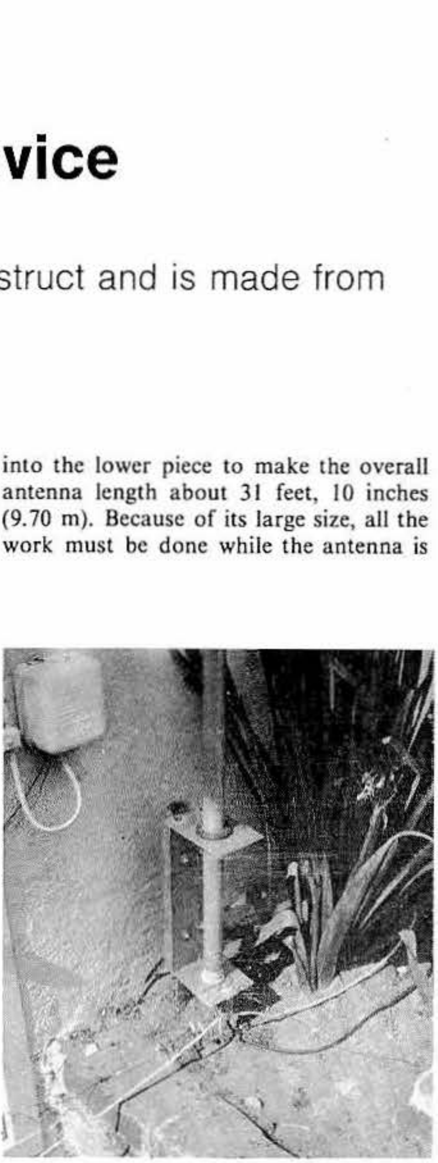
Knowing of a Novice who had space problems, the author set out to design an antenna for him that could be used on 40 and 15 meters. His previous antenna was a horizontal "V" whose performance wasn't worth the time it took to put it up. Because of his narrow property, the angle between the two wires was only around 40 degrees, no doubt causing considerable signal cancelation. Horizontal antennas were ruled out, so the best antenna for him was a vertical.

Knowing (or caring) little about multiband trap-loaded antennas, it was decided the simplest antenna would be a quarter-wavelength vertical on 40 meters. After a little paper work, and using formulas given in *The ARRL Antenna Book,* the correct length would be 31 feet 10 inches (9.70 m) for 7.175 MHz. This length would also work as a 3/4-wavelength antenna on 15 meters, providing two-band coverage. However, a 32-foot (9.75-m) vertical antenna made roof-mounting too difficult! Mounting the vertical to the side of the house alleviated many guying and support problems.

Materials

The first concern was what to use for antenna materials. Being almost 32 feet high, the vertical would need strength, so the writer thought of steel tubing, but that was much too expensive. With conduit there aren't enough sizes offered, and that left only one more material — aluminum tubing. The latter comes in just about any size desired, and the author had no trouble in finding just what he wanted. Going to the nearest aluminum dealer, the author found his stock to be more than ample.[1]

In order to keep the cost minimal, the author decided to make the base piece from 1-inch (25-mm) diameter thin-wall tubing. Into 12 feet (3.66 m) of this was inserted a 12-foot piece of 7/8-inch (22-mm) diameter thin-wall tubing. This piece was telescoped 2 feet (0.610 m), then bolted and clamped (after the end had been slit twice by a pair of tin snips). It was necessary to use hose clamps on the tubing because the galvanized bolts didn't provide a good bond between the pieces. The top section was 13-1/2-foot (4.11-m) piece of 3/4-inch (19-mm) diameter thin-wall tubing inserted far enough into the lower piece to make the overall antenna length about 31 feet, 10 inches (9.70 m). Because of its large size, all the work must be done while the antenna is



Here is the base mount, installed on the side of the house. The two white wires coming out from the base are the radials.

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[1] [Editor's Note: TV mast material is also well suited for verticals and comes in 10-foot (3.05-m) lengths, either steel or, preferably, aluminum.]

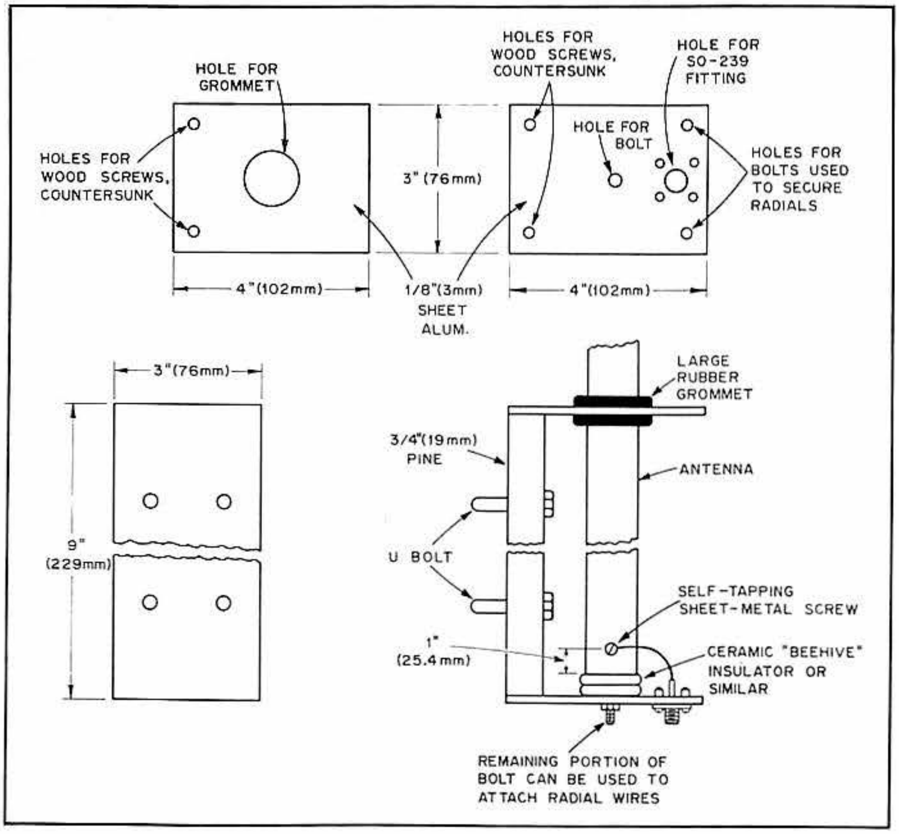

HOLE FOR GROMMET
HOLES FOR WOOD SCREWS, COUNTERSUNK
4"(102mm)
HOLES FOR WOOD SCREWS, COUNTERSUNK
3"(76mm)
1/8"(3mm) SHEET ALUM.
HOLE FOR BOLT
HOLE FOR SO-239 FITTING
HOLES FOR BOLTS USED TO SECURE RADIALS
4"(102mm)
3"(76mm)
9" (229mm)
LARGE RUBBER GROMMET
3/4"(19mm) PINE
ANTENNA
U BOLT
SELF-TAPPING SHEET-METAL SCREW
1" (25.4mm)
CERAMIC "BEEHIVE" INSULATOR OR SIMILAR
REMAINING PORTION OF BOLT CAN BE USED TO ATTACH RADIAL WIRES

Fig. 1 — Details for making the base-mounting section of the vertical.

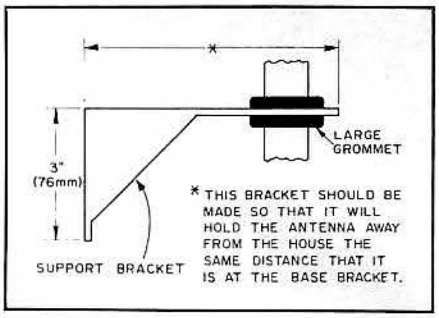

*
LARGE GROMMET
3" (76mm)
* THIS BRACKET SHOULD BE MADE SO THAT IT WILL HOLD THE ANTENNA AWAY FROM THE HOUSE THE SAME DISTANCE THAT IT IS AT THE BASE BRACKET.
SUPPORT BRACKET

Fig. 2 — Details for the support bracket.

lying on the ground. Then, the antenna must be disassembled and put up piece by piece. (Do not attempt to put the antenna up in one piece! While the weight isn't excessive, the tubing cannot stand the strain.)

Putting It Up

The original base bracket was made from 3/4-inch (19-mm) pine, but during the first rain the wood got wet and the bracket turned out to be a very poor insulator. So the unit was redesigned to use two pieces of 1/8-inch (3-mm) thick sheet aluminum, a large grommet, and a ceramic standoff insulator (see Fig. 1).

Assembling the two-band vertical was quite simple. First, a 4-foot (1.22-m) stake was driven into the ground about 2-1/2 feet (0.76 m), and about four or five inches (102 or 127 mm) away from the side of the house. Next, the bottom section (with the bracket attached) was slipped over the stake and tightened in place with the U bolts. Then the second section was inserted into the first, clamped and bolted in place. A support bracket was made from scrap aluminum, and a large grommet was installed on it to insulate the antenna from the brace (see Fig. 2). This assembly was then attached to the side of the house (near the gable) with wood screws. Last, the third section was forced through the grommet in the second bracket, and was then inserted into the second piece and clamped. (If adjustment of resonance is desired, it is better not to bolt the final section). A suitable cap was mounted on top of the antenna to keep out moisture.

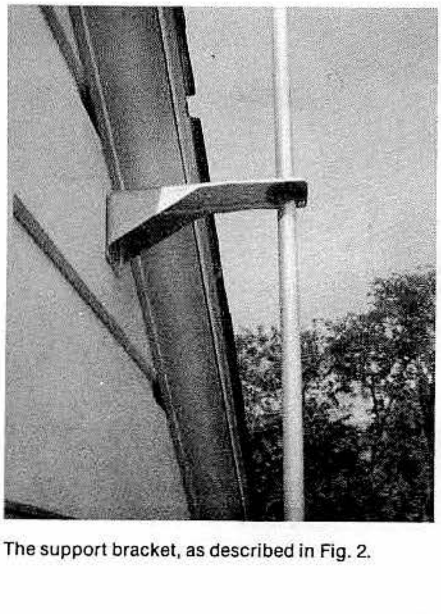
Tune Up

RG-58/U coax was then connected between the transmitter and antenna with an SWR bridge in the line, and power was applied at 7175 kHz. The SWR was found to be 3:1. This was without any ground system on the antenna. In order to obtain a better match and reduce the SWR, it was apparent that a ground system was required.

According to *The ARRL Antenna Book*, two methods of making a suitable ground system can be used. One way is to connect the coax outer shield directly to ground at the base of the antenna, via a ground rod. However, this doesn't work too well unless the soil is extremely conductive (his wasn't). The other method is to make up some sort of artificial ground in the form of radials.

The author cut a radial from some surplus wire to the same length as the vertical section, attached the radial to the base plate and the SWR dropped to 2:1. Unknown to the author at the time, *The Antenna Book* says that the radials should be 2.5 percent longer than the vertical itself, so actually, they should have been made 32-feet 7-3/4-inches (9.95-m) long. A second radial, similar to the first, was attached and the SWR dropped further (to about 1.4:1). When the soil was wet, such as after a rain or after watering, the SWR takes a nose dive to less than 1.2:1. Since the property space was limited, two radials were all that could be used. Ideally, the most perfect system would consist of a metal disk, one quarter wavelength in radius, buried a few inches below the earth's surface, but this approach is rather impractical! But if the antenna was to be erected in an area *away* from buildings, and guyed, a ground system could be made of chicken wire or other similar material. However, the more radials, the better the artificial ground. Also, they should be laid out in as nearly a spoke-like pattern as possible. Hy-Gain recommended for their AVQ series antennas that a radial system be used consisting of at least two radials for *each* band used. However, for this installation the 40-meter radials operate on their third harmonic at 15 meters, requiring but one set of wires.[2]

The length specified makes the antenna resonant at about 7175 kHz on 40 meters. On 15 meters, at the third harmonic, the antenna is resonant at about 21,425 kHz, but power was applied as low as 21,105 kHz,



The support bracket, as described in Fig. 2.

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[2] [Editor's note: Actually, *any* radials, regardless of length, will help the performance of the system. Also when used on 15 meters, the antenna would be three quarter wavelengths long with low-impedance feed, approximately 50 ohms. However, the angle of radiation from the antenna will be higher than that of a quarter-wavelength vertical.]

and the SWR appeared to be only 1.4:1, well within tolerable limits. Bandwidth on both Novice bands was essentially flat.

Additional Information

Total cost will depend greatly on the individual's ability to scrounge parts. If the builder prefers to purchase the principal materials, this list will be useful.

- 3 — pieces thin-wall aluminum tubing, 1- (25-mm), 7/8- (22-mm), and 3/4-inch (19-mm) diameters. 12 (3.66 m), 12 (3.66 m) and 13-1/2 feet (4.11 m) long, respectively.
- 2 — U bolts.
- 1 — SO-239 connector.

The other material, including three bolts and nuts, six wood screws, two grommets, two hose clamps, wood and aluminum for brackets, ground stake, and cap will vary from no cost to a few dollars, dependent on available materials. If used or surplus tubing is available one could save a substantial amount of money.

In this instance, the top of the antenna extends about 16 feet (4.88 m) above the peak of the roof, but because of the bracing no guy wires were necessary. If the antenna is to be erected in a high-wind area, guys made from nonconducting monofilament fishing line (or other nonconducting line) could be used.

The owner has received nothing but glowing reports so far. Running about 70 watts input, the first CQ on 40 meters raised W9SVJ in northern Indiana from Glendale, CA. His report, RST 589. On 15 meters the owner has worked ZL3JC, AX7SM and JH1EZZ, and received very good reports.

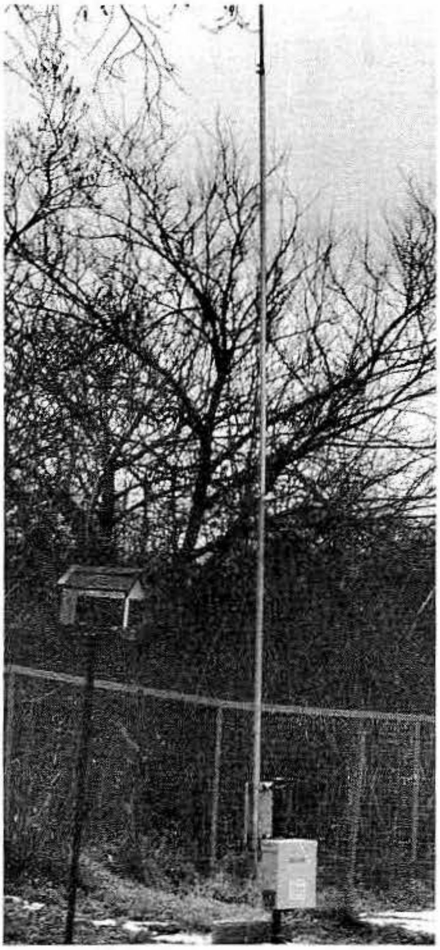
This vertical has no gain, and probably couldn't come near a Yagi or a quad in performance, but for an antenna costing less than $10 it does one heck of an FB job. This material was originally presented in *QST* by Jerry Arnold, WA6MBP.

Build This Novice Four-Band Vertical

Putting your first amateur station together can be an expensive proposition. One way to cut costs is to keep the antenna simple. Here's how to shave the price and provide four-band operation.

Is operation with one antenna acceptable if it covers the 80-, 40-, 15- and 10-meter bands? For a new Novice that's a reasonable approach. The author's backyard is smaller than that of most urban homes, so full-size dipole or inverted-V antennas were out of the question. Not owning a tower (yet!), it seemed that a ground-mounted vertical antenna would be worth trying.

After reading *The ARRL Antenna Book*, it was decided that a ground-mounted vertical antenna would be easiest to build. Some radial wires could be buried, and the metal fence which encloses the backyard could also be hooked up to enlarge the ground system. The author preferred this type of antenna to one installed above ground, because radials of specific lengths for each of the four bands would have been needed for a roof-mounted, groundplane type of vertical. The buried wires for the ground-mounted antenna could be any convenient length, as long as the available space would permit. From what was read about these antennas, the author believed that reasonable performance could be had even if the ground radials weren't numerous and long, although generally the more, the better.



The completed 4-band vertical antenna used at WB1FSB. The box at the base of the antenna contains a loading coil.

With the help of W1FB some used aluminum tubing was purchased that would telescope together and give the author a 25-foot (7.62-meter) antenna. The wall thickness of the tubing is 0.058 inch (1.5 mm). Three 10-foot (3.05 m) sections are used. The largest diameter is 1 inch (25 mm). The center telescoping section has a diameter of 7/8 inch (22 mm) and the top piece of tubing has a 3/4-inch (19-mm) diameter. This material, plus hose clamps for holding the sections together, came to $8. An old ceramic rotary switch, a coaxial connector, a feed-through bushing, and a piece of Air Dux coil stock were acquired at a flea market for an additional $3. Two medium-size, ceramic standoff insulators were donated by W1FB. He said they cost him 50 cents each at a swap session. All that remained to collect was a weatherproof box for the loading coil, some 50-ohm coaxial cable and six U bolts. The author's OM, Bob, found some used 1-1/2-inch (38-mm) steel pipe which is 7 feet (2.13 m) long. It is used as a support for the vertical.

Constructing the Antenna

A lawn-edger tool was used to make slits in the lawn, out from the base of the antenna toward the edges of the backyard. The slits were cut to a depth of 2 inches (51 mm). A total of 10 radials were buried in the slits. Some are only 15 feet (4.57 m) in length, while others are 25 feet (7.62 m) long. The metal yard fence was bonded together as needed, using wire jumpers between the fence sections. A single buried wire joined the fence to the common ground point at the base of the antenna.

The OM drove the steel pipe into the ground to a depth of 4 feet (1.22 m), leaving 3 feet (0.91 m) above ground for attaching the vertical antenna and weatherproof box. Construction details are shown in Fig. 3.

Although a wooden box could have been used to house the loading coil, switch and other hardware, an old electrical housing that the author's OM had in his junk box was used (Fig. 4.). It was drilled and

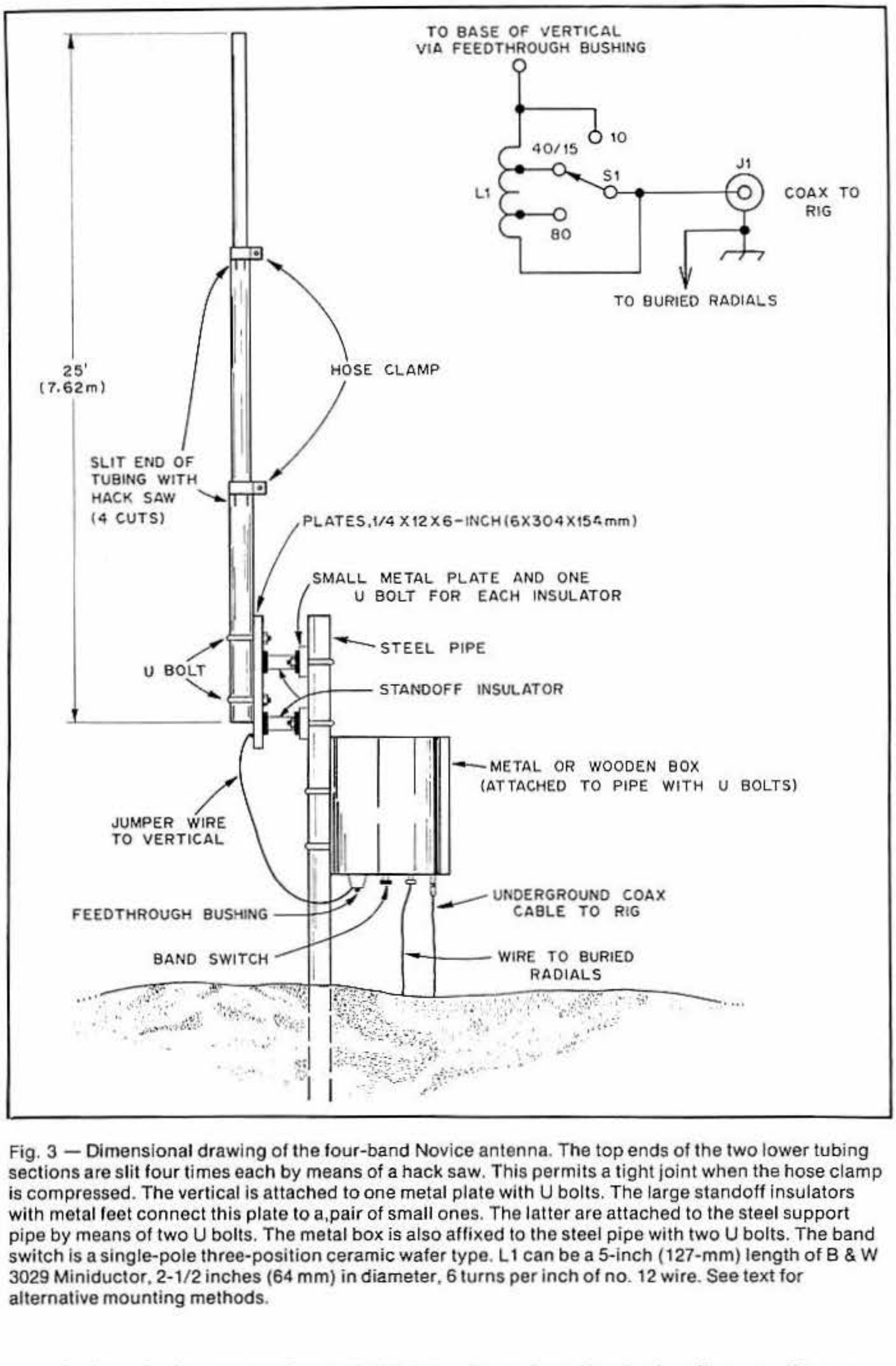


Fig. 3 — Dimensional drawing of the four-band Novice antenna. The top ends of the two lower tubing sections are slit four times each by means of a hack saw. This permits a tight joint when the hose clamp is compressed. The vertical is attached to one metal plate with U bolts. The large standoff insulators with metal feet connect this plate to a,pair of small ones. The latter are attached to the steel support pipe by means of two U bolts. The metal box is also affixed to the steel pipe with two U bolts. The band switch is a single-pole three-position ceramic wafer type. L1 can be a 5-inch (127-mm) length of B & W 3029 Miniductor, 2-1/2 inches (64 mm) in diameter, 6 turns per inch of no. 12 wire. See text for alternative mounting methods.

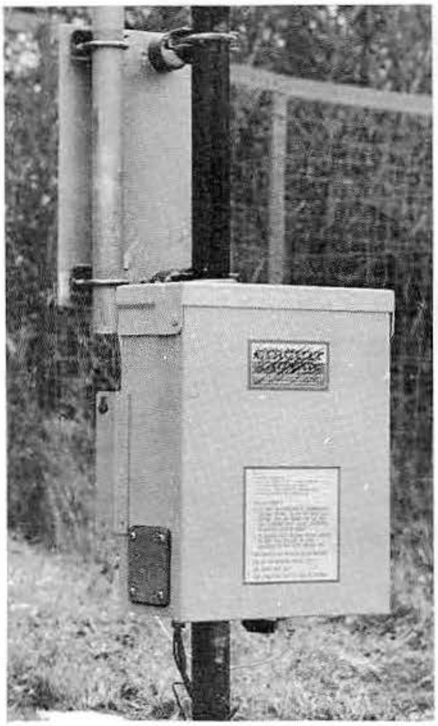


Fig. 4 — Closeup view of the base of the vertical. The aluminum tubing is affixed to a metal plate. The latter is attached to the iron support pipe by means of two surplus standoff insulators. Small aluminum plates are attached to the ends of the insulators to permit them to be fastened to the iron pipe by means of U bolts. The radial wires are connected to the bottom of the coil-housing box.

Fig. 5 — The author checks the SWR of the antenna during final adjustment of the system.

punched on the bottom surface to hold the feedthrough bushing, coaxial connector, switch and ground terminal for the radials.

W1FB designed the antenna, but he wasn't sure that an acceptable impedance match could be had on all four bands without a complex matching network. It was decided to try his idea, so the installation was completed.

Adjusting the Vertical

The author helped her OM install the antenna, then called W1FB for some assistance in tuning the system. He thought we could tune the vertical for 40 meters and make it work okay as a 3/4-wavelength vertical on 15 meters. For use on 80 meters it would be fairly short (63 feet or 19.20 m is the correct length for 3.7 MHz). With base loading it should offer adequate service out to a few hundred miles on 80 meters. Finally, it would operate as a 3/4-wavelength vertical on 10 meters.

A homemade SWR indicator was hooked in the coaxial line at the base of the vertical.[1] A small amount of transmitter power (5 W) was applied at 3725 kHz and the 80-meter switch lead was touched on the turns of the coil until minimum reflected power was indicated (Fig. 5). An SWR of 1:1 was obtained. The wire was then soldered in place on the coil. Next power was fed to the antenna on 7125 kHz, and the 40-meter switch lead was touched to the coil turns until an SWR of 1:1 was read. While using the same coil tap power was supplied to the antenna on 21.1 MHz and the SWR checked. It was approximately 3:1. By moving the coil tap just one turn we were able to get an SWR of 1.5:1 on 15 meters. A recheck on 40 meters followed. The SWR for that band was less than 2:1 — not a bad compromise! The coil was bypassed entirely for operation on 10 meters: an SWR of 2:1

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[1] DeMaw, "A QRP Man's RF Power Meter," *QST*, June 1973.

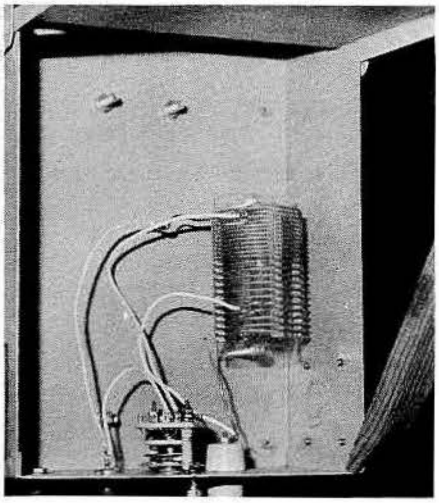


Fig. 6 — Interior view of the coil housing showing the switch, feedthrough bushing, coaxial connector, and ground post for the radials. The coil shown is a piece of Air Dux stock with a tapered pitch. It was obtained at a flea market.

was indicated at 28,000 kHz. The length of the overall antenna for operation on 28,100 kHz should be 25 feet or 7.62 m (3/4-wavelength radiator). However, the switch leads inside the coil housing add to the antenna length. If an SWR of less than 2:1 is desired, break the 10-meter switch lead and insert a 100-pF air variable capacitor. The unwanted reactance can be tuned out by this means and a low SWR will result.

Opening and closing the cover of the metal box had only a minor effect on the SWR. At last an on-the-air test of the system was possible. Fig. 6 shows the interior of the coil and switch housing.

Results

Good signal reports have been received on all bands. The first QSO on 40 meters netted an RST 599 report from North Carolina and many similar reports followed on 80, 15 and 10 meters. The author feels that a WAS award is not too far away now that this antenna is in operation.

An Alternative

There are many ways you can duplicate this design using substitute materials. For example, electrical conduit with couplers between the sections should be satisfactory in place of the aluminum tubing. The entire structure could be made from 2 x 4 inch (51 x 102-mm) lumber. If that is done, the radiator could even be a 25-foot (7.62 m) piece of no. 10 wire, supported on the side of the wood with standoff insulators.

Instead of the mounting method shown in Fig. 3, the vertical pipe could probably be inserted into a 2-foot (.61-m) length of PVC tubing, then clamped to the mounting plate. This would eliminate the need for the two standoff insulators. Better still, four or five wraps of Teflon sheeting (10 mil or 0.25 mm thickness) could be placed over the bottom end of the vertical before clamping it in place on the mounting plate. Teflon can be purchased at most plastic-supply houses.

The author hopes this idea is useful to other Novices who are trying to keep the budget within reasonable limits. This writer likes the way the antenna is working. Others should have good luck with this antenna also. Oh, by the way, the ground radials are made from various scraps of wire. The size isn't important, and they can be insulated or bare. There is quite an assortment of wire types buried in the lawn! This material was originally presented in *QST* by Marian Anderson, WB1FSB.

The Cheapie GP

Keeping an ear on 10 and 15 meters? With the trend of rising solar flux, 15 meters "opens" nearly every day — 10 meters occasionally. Don't miss these openings. Build a Cheapie GP!

Looking for an antenna to cover the 10- and 15-meter bands that won't pinch your pocketbook? Should it contain easy to obtain items and be relatively simple to construct while using ordinary hand tools? Must it be physically small and not a neighborhood eyesore? If your answer to these questions is "yup," you've turned to the right page! Detailed here is a duo-band coaxial-cable-fed, trap groundplane antenna system.

A groundplane antenna consists of a vertical quarter-wavelength radiator and an artificial metallic ground system extending radially from its base. For good results the antenna should be mounted at least one-quarter wavelength above ground. This is approximately 12 feet (3.66 m) on 15 meters. At this height and higher, only four radials for each band are necessary to provide a good ground system. If this antenna was ground mounted, many more radials would be needed to reduce earth losses to an acceptable low level. The antenna has an omnidirectional horizontal or *H*-plane pattern which means radiation from the antenna is essentially the same in all horizontal directions as shown in Fig. 7A. In Fig. 7B the approximate vertical or *E*-plane pattern of the antenna is shown for the antenna mounted one-quarter wavelength above ground. As can be seen, maximum radiation occurs at the low angles above the horizontal plane of the antenna. The antenna has an overhead null so little energy is radiated at high angles. This does not detract from the usefulness of the antenna, since DX signals seldom arrive at high angles on these bands. Instead, maximum radiation is concentrated at the *lower angles* where it will be more effective. Conversely, a horizontal dipole mounted one-quarter wavelength or less above ground will have maximum radiation straight up or nearly so. Lower-angle radiation will not occur unless the dipole is raised to a height of one-half wavelength or more above ground. If it is not possible to mount your horizontal antenna a half wavelength above ground, the vertically polarized groundplane is perhaps the logical choice over a dipole. As a general rule, the higher the groundplane can be located above power lines, gutters, house wiring and the like, the better it will perform.

A Duo-Band System

For the antenna to perform properly on two bands, it must function as a *separate* groundplane vertical on each band. This requirement is met quite simply in the case of the radials since four radials are used for each band. The 10-meter radials are 8 feet, 5 inches (2.56 m) long and the 15-meter radials are 11 feet, 7 inches (3.53 m). When the antenna is operated in the 10-meter mode, the 15-meter radials have little effect on the system. Similarly, when the antenna is used on 15 meters, the 10-meter radials do not appreciably alter the operation of the antenna. The effect of the additional radials is to change slightly the feed point resistance and the resonant frequencies of the antenna.

The vertical member of the antenna must act as a quarter-wavelength radiator on both 10 and 15 meters. To accomplish this a trap is inserted in the 15-meter vertical section. Its approximate location is a

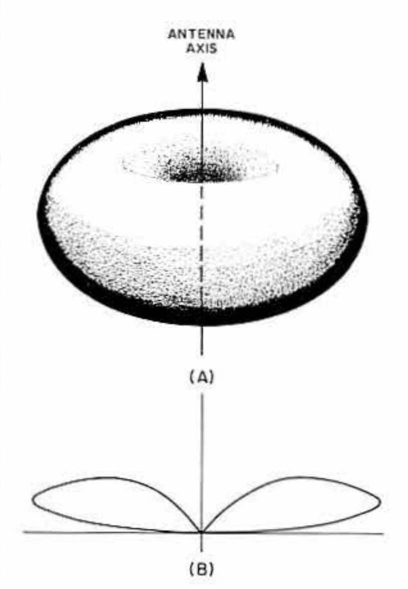


Fig. 7 — (A) Horizontal or H-plane pattern of the groundplane. (B) Approximate vertical or E-plane pattern of the antenna.

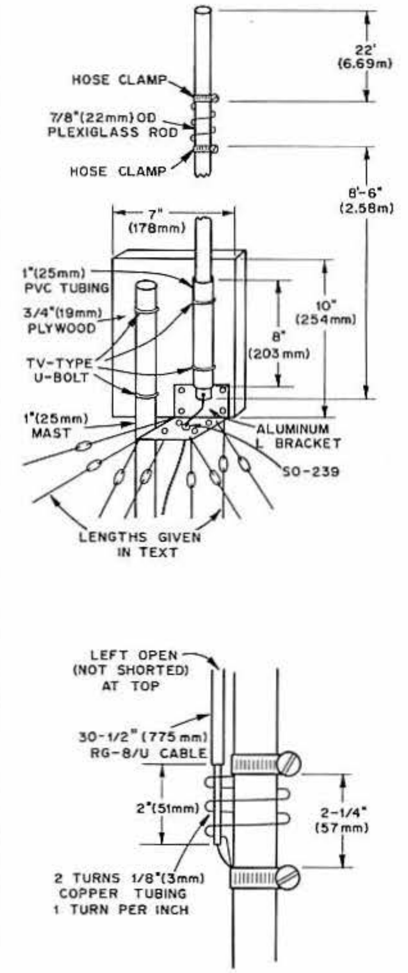
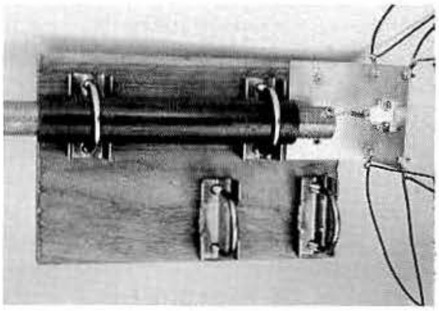
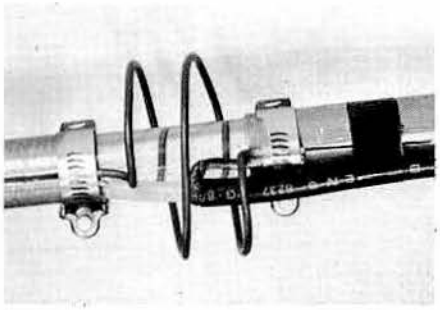


Fig. 8 — Constructional details of the duo-band antenna system.



A photograph of the base assembly. The SO-239 coaxial connector and hood can be seen in the center of the aluminum L bracket. The U bolts are TV-type antenna hardware. The plywood should be coated with varnish or similar material.



A close-up view of the trap. The leads from the coaxial-cable capacitor should be soldered directly to the pigtails of the coil. These connections should be coated with varnish after they have been secured under the hose clamps.

10-meter quarter wavelength above the base. The trap has a high impedance on 10 meters, thereby electrically divorcing the top section of the antenna when it is operated on that band. The length of the 10-meter section (section below the trap) is somewhat shorter than that of a simple 10-meter-only quarter-wavelength vertical. This is because the trap and top section of the duo-band system add top loading to the 10-meter portion of the antenna, reducing the length required for quarter-wavelength resonance. A coaxial-cable capacitor and a coil made from copper tubing form the trap which is resonant at approximately 28.150 MHz. On 15 meters the trap has a low impedance, effectively connecting together those portions of the antenna above and below the trap. The overall length of the 15-meter radiator is a bit shorter than a simple quarter-wavelength radiator would normally be for that band. This is because at 21 MHz the trap introduces inductance into the radiator — similar to the effects of a loading coil.

Construction

The vertical section of the antenna is mounted to a 3/4-inch (19-mm) thick piece of plywood board that measures 7 X 10 inches (178 mm X 254 mm). Several coats of exterior varnish or similar material will help protect the wood from inclement weather. Both the mast and the radiator are mounted to the piece of wood by means of TV U-bolt hardware. The vertical is electrically isolated from the wood with a piece of 1-inch (24-mm) diameter PVC tubing. A piece approximately 8 inches (203 mm) long is required, and it is of the schedule-80 variety. To prepare the tubing it must be slit along the entire length on one side. A hacksaw will work quite well. The PVC fits rather snugly on the aluminum tubing and will have to be "persuaded" on with the aid of a hammer. The mast is mounted directly to the wood with no insulation. An SO-239 coaxial connector and four solder lugs are mounted to an L-shaped bracket made from a piece of aluminum sheet. A short length of test probe wire, or inner conductor of RG-58/U cable, is soldered to the inner terminal of the connector. A UG-106/U connector hood is then slid over the wire and onto the coaxial connector. The hood and connector are bolted to the aluminum bracket. Two wood screws are used to secure the aluminum bracket to the plywood as shown in the drawing and photograph. The free end of the wire coming from the connector is soldered to a lug which is mounted to the bottom of the vertical radiator. Any space between the wire and where it passes through the hood is filled with GE silicone glue and seal or similar material to keep moisture out. The eight radials are soldered to the four lugs on the aluminum bracket. The two sections of the vertical member are separated by a piece of clear acrylic rod. Approximately 8 inches (203 mm) of 7/8-inch (22-mm) OD material is required. The aluminum tubing must be slit lengthwise for several inches so that the acrylic rod may be inserted. The two pieces of aluminum tubing are separated by 2-1/4 inches (57 mm).

The trap capacitor is made from RG-8/U coaxial cable and is 30.5 inches (775 mm) long. RG-8/U cable has 29.5 pF of capacitance per foot and RG-58/U has 28.5 pF per foot. RG-8/U cable is recommended over RG-58/U because of its higher breakdown-voltage characteristic. The braid should be pulled back 2-inches (51 mm) on one end of the cable, and the center conductor soldered to one end of the coil. Solder the braid to the other end of the coil. Compression-type hose clamps are placed over the capacitor/coil leads and put in position at the edges of the aluminum tubing. When tightened securely, the clamps serve a two-fold purpose — they keep the trap in contact with the vertical members and prevent the aluminum tubing from slipping off the acrylic rod. The coaxial-cable capacitor runs upward along the top section of the antenna. This is the side of the antenna to which the braid of the capacitor is connected. A cork or plastic cap should be placed in the very top of the antenna to keep moisture out.

Installation and Operation

The antenna may be mounted in position using a TV-type tripod, chimney, wall or vent mount. Alternatively, a telescoping mast or ordinary steel TV masting may be used, in which case the radials may be used as guys for the structure.

Any length of 50-ohm cable may be used to feed the antenna. The SWR at resonance should be on the order of 1.2 to 1.5:1 on both bands. The SWR is not 1 because the feedpoint resistance is something other than 50 ohms — closer to 35 or 40 ohms. Nearby metallic objects may also have an effect on the impedance of the antenna. The antenna is resonant at approximately 21.150 MHz and 28.150 MHz.

Some amateurs place too much importance on obtaining a "no reflected power" reading on their SWR indicators. Most ham transmitters will load into lines which exhibit an SWR of up to 2:1, the exception being some of the new broadband, no-tuning transmitters. To demonstrate how little effect an SWR of 1.5 or 2:1 will have on the system, consider the following: If the antenna is fed with 100 feet (30.48 m) of RG-8/U cable and if the antenna is perfectly matched to the line (an SWR of 1), the power loss along the cable will be approximately 0.98 dB on 10 meters. If the SWR on the line is increased to 1.5:1, the additional loss on the line due to the higher SWR is less than 0.1 dB. If the SWR is increased to 2:1, the additional loss over that of the matched condition will be on the order of 0.2 dB. This amount of loss is insignificant, and for this reason a complicated matching network is not necessary. This material was originally presented in *QST* by Jay Rusgrove, W1VD.

A High-Performance, 20-, 40- and 80-Meter Vertical System

Urban dwellers with small lots take heart! Here are the details for building your own DX-effective three-band mini-vertical antenna. Cost-conscious amateurs will be happy with the low cost of this system.

In another article on vertical antennas,[1] we tried to point out some fundamental characteristics of ground-mounted verticals, namely: (1) a good image plane is necessary for efficient operation, (2) a vertical over a good image plane compares favorably with a dipole at an elevation of one-half to one wavelength, (3) a short vertical compromises little in the way of performance.

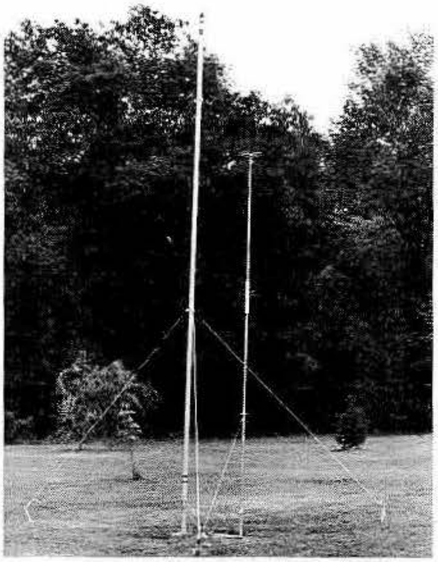
This paper describes a highly efficient, three-band vertical system for 20, 40 and 80 meters, using elements of the order of an eighth wavelength. The system consists of an 80-meter vertical in parallel with a 20/40-meter trap vertical. Actually, either the 80-meter or the 20/40-meter vertical can be constructed and used alone if one is not interested in triband operation. The input impedances of both antennas are 12-1/2 ohms and they use the same 4:1 matching transformer.[2] The antennas also use the same radial system consisting of 100 radials of no. 15 aluminum wire 50 feet (15.24 m) in length (a lesser number of radials can be used as is discussed later in the article). Because of expected lower sunspot activity and, hence, poorer propagation conditions on the higher bands, the 40- and 80-meter portions of this antenna system, in particular, should prove very effective in DX communication over the next few years.

The first part of this paper deals with the design and tune-up considerations of the 80-meter element; the second part with the 20/40-meter element and the way it is used with the 80-meter vertical forming an efficient triband system. This is followed by reports on performance. Reference is also made to other alternatives for a multiband vertical system.

80-Meter Vertical

The two considerations in designing the 80-meter element of this vertical system were: (1) a good bandwidth for a reasonable height (a height one person can handle); and (2) proper spacing between the 80 and 20/40 portions such that coupling is negligible and both can be used over the same radial system.

Prior to building the shortened vertical described in this article, two others were constructed and tested on the air. One was a 22-foot (6.71 m) vertical[3] which had a 65-kHz bandwidth. The other was a trap vertical[4] with only a 20-kHz bandwidth. Both of these antennas were used separately over the same image plane of 100 radials and were efficient radiators. Therefore, the main reason in going to a slightly longer antenna was simply *to obtain a broader bandwidth.* The eighth-wavelength vertical on 40 meters from the previous work[5] promised considerable improvement by adding only a few feet. The results are shown in Figs. 9 and 10. The total height turned out to be 29 feet (8.83 m). This resulted in a bandwidth of about 140 kHz, a little more than twice the bandwidth of the 22-footer (6.71 m).



The triband vertical showing the polypropylene guys which provide an extra margin of support.

The vertical, in Fig. 9, uses a 20-foot (6.10-m) section of thick-wall aluminum tubing. (It was used some years ago as a gin pole for erecting a beam on a 40-foot (12.2 m) tower.) An 8-foot (2.44 m) extension was constructed with 1-inch (25-mm) tubing bolted in place using spacers for centering. The insulator at the bottom is phenolic tubing with a canvas base.[6] It has a 1/2-inch (13-mm) thick wall, is 9 inches

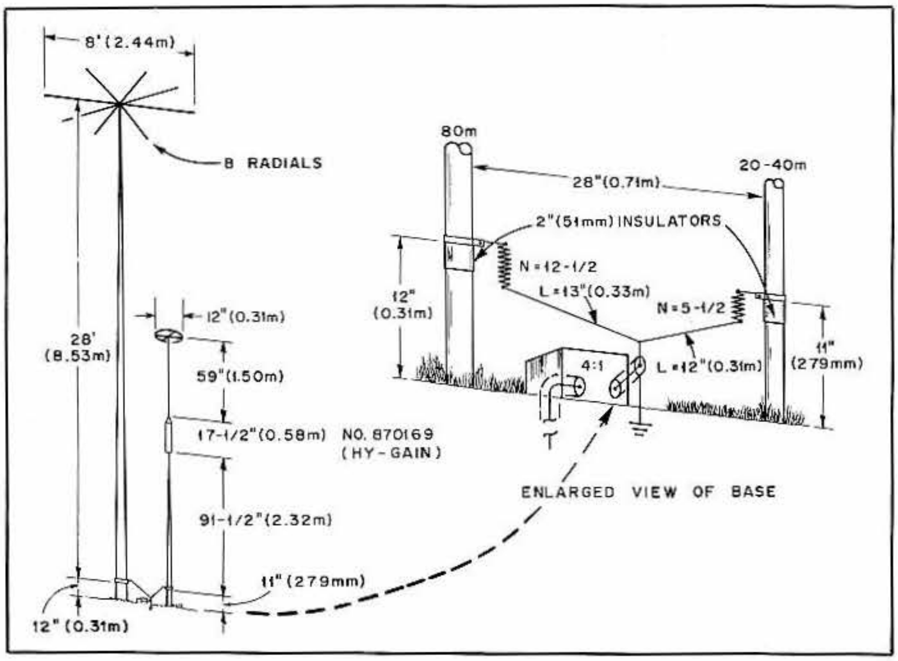
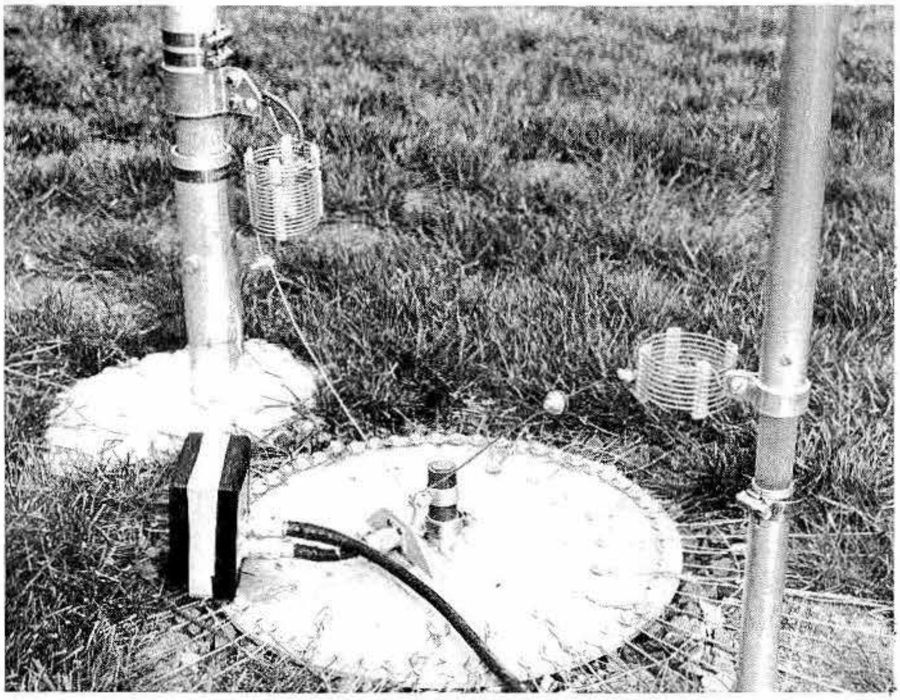


Fig. 9 — The 20-, 40- and 80-meter vertical antenna system. Tuning and construction details are given in the text.



Close-up of the base of the triband vertical antenna.

(229 mm) long and has an ID of 1 inch (25-mm). The bottom aluminum tubing supporting the antenna is 3-1/2 feet (1.06 m) long with 2-1/2 feet (0.76 m) of it placed in cement. The diameter of the hole in the ground is about 1 foot (0.31 m). Even though this construction could probably be self-supporting, three simple polypropylene guys at about the 7-foot (2.13-m) level are used for extra margin of support. The radials at the top use 1/2-inch (13-mm) aluminum tubing.[7] The base loading consists of 12-1/2 turns of a B&W 3029 coil.[8] Actually, 14 turns are on the coil. A shorting stub, as shown in the close-up picture of the base of the two antennas, is used for adjustment. To place the minimum SWR near the low end of the phone band, where much of the DX is worked, 1-1/2 turns were shorted out. The final number of turns employed depends, to some extent, on the number of radials used in the image plane. A simple check is to set the shorting tap at some convenient point, like 12 or 13 turns, and plot the SWR. If the minimum value appears too high in frequency, then add about a half a turn of coil. This half turn chould change the position of the minimum SWR value by about 50 kHz. As can be seen in Fig. 10, the minimum value of SWR is practically 1:1 and occurs at 3.840 MHz. This also verifies the input impedance value of 12-1/2 ohms, as expected from the previous work on short verticals.

20/40-Meter Vertical

In extending the operation of a vertical system over other bands, many alternatives are available. A trap vertical with a 12-1/2-ohm input impedance can be connected in parallel with the 80-meter vertical. Alternatively, the trap vertical can be designed to present an impedance of 50 ohms and thus be connected to the input side of the 4:1 transformer.[9] If broadband operation is desired on only 80 and 40 meters, then one-eighth wavelength verticals on both bands can be used.[10]

For this work, a 20/40-meter trapped vertical having an input impedance of 12-1/2 ohms was used. It offered a rather simple mechanical form of parallel operation as is shown in Fig. 9 and the close-up picture. The bandwidth on 40 meters of 155 kHz appeared acceptable. This bandwidth can be extended by about 50 percent by using the 50-ohm design of a trap vertical.

In the first attempt of parallel operation, the 20/40-meter vertical was placed only 14 inches (355 mm) away from the 80-meter vertical. The coupling appeared excessive. The 80-meter vertical was detuned by approximately 50 kHz. The 20/40-meter vertical also required excessive base loading in order to present an acceptable input impedance. By doubling the spacing between the verticals to 28 inches (711 mm), the interaction between them became negligible. The final values of heights and loadings were practically the same as if the elements were operating alone.

The adjustment of the 20/40-meter vertical is somewhat more complicated than the 80-meter vertical. An impedance bridge, as described in the *ARRL Handbook*, is of considerable help. In this case, there are two degrees of freedom: (1) varying the number of turns at the base, and (2) adjusting the lengths of the vertical sections.

Basically, the tuning is as follows: The tap is set at about 5-1/2 turns and the 20-meter section adjusted to give an acceptable value of SWR, both in position in the band and in magnitude. If the impedance is too high, it can be lowered by increasing the number of turns and lowering the height of the 20-meter section for resonance. After this, the 40-meter portion is then tuned. A plot of the SWR vs. frequency can immediately give an indication of the necessary adjustment of the section above the 20-meter trap. If the minimum value appears too low in frequency, a shortening of the top section is required. In no case should large adjustments be made. A change of a few

Table 1

Some Results With Triband Vertical

Date	*Station Contacted*	*W2FMI Signal Report*	*Freq.(MHz)*	*Input Power SSB (Peak)*	*Comments*
3/13	K5LWL/YV6	59 + 10 dB	7	2 kW	very, very strong signal, only one signal stronger — he used a Yagi at 120 feet (36.58 m)
4/3	WB5HJY	59 + 40 dB	7	2 kW	superior to anything on band
4/4	ZF1SP	59 +	14	2 kW	very, very nice signal
4/4	WA4MUR/4	59 + 40 dB	14	2 kW	best signal on whole band
4/18	KV4HW	59 + 10 dB	7	2 kW	loudest on band
5/9	K6YIY	59	4	2 kW	K1GZL and I are only ones they hear
5/9	W9LZX	59 + 30 dB	4	2 kW	strongest (very consistent signal)
5/12	W2DU	59 +	4	2 kW	tremendous signal
5/17	VK5PB	56-7	4	2 kW	remarkably strong
5/17	W4JNY	59 + 20 dB	4	2 kW	outstanding, certainly one of best
5/22	VK5PB	59 + 10 dB	7	2 kW	really amazing
5/23	ZL3RJ	57-8	4	2 kW	one of the strongest he's heard for some time — pinned the S meter
5/27	WA2BQL	59 + 30 dB	4	200 W	very potent — Stronger than most locals — couldn't believe you were using 200 W

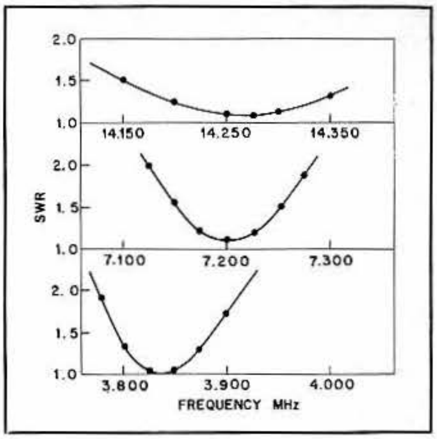


Fig. 10 — Standing wave ratio vs. frequency for the 20-, 40-, and 80-meter vertical antenna system.

inches has considerable effect. If the input impedance on 40 meters appears too low, then the 20-meter section has to be lengthened. This requires that the whole procedure be repeated. In any case, the initial adjustment should be started on the highest band of the trap vertical.

Results

Short verticals have been used by the author during the past year with considerable success. Many DX contacts were made on 40 meters with antennas varying in length from 6 to 33 feet (1.83 to 10.05 m). Since an extensive ground system was used, very little difference in effectiveness was noticed between the antennas.[11] This even includes redesigned trap verticals. As was stated before, the objective of the present investigation was to design a three-band vertical system which not only yielded competitive antennas on the lower bands, but one that was capable of covering a considerable portion of 80 meters. As was seen, a separate one-eighth wavelength antenna connected in parallel with a trap vertical not only gave a bandwidth on 80 meters of 140 kHz where the SWR was less than 2:1, but was short enough to not require considerable help in erection.

During all this time of operation of short verticals on 40 meters, and as of this writing, including several months on 80 meters, very few signal reports were received which did not indicate one of the best signals on the band. Table 1 gives some of the reports and comments received. In only three specific cases on 40 meters have the short verticals been bested by other antenna systems. One is shown in Table 1 where K5LWL/YV6 reported a stronger stateside signal by an amateur using a Yagi at 120 feet (36.58 m). The other cases include a comparison with W2GO of Linden, NJ. On 40 meters, VK5PB reported 6 dB and VK2WC 10 dB in favor of W2GO's signals. He was using a two-element Yagi at 60 feet (18.28 m). The elements were 44-1/2 feet (13.56 m) in length and the boom, 20 feet (6.10 m). On 80 meters, only one other station received a stronger report on direct comparison. This was by W2HCW, when comparing my signals with VK5PB. The difference was 2 to 3 S units. His antenna was an 80-meter Yagi at 120 feet (36.58 m).

Invariably, most amateurs were surprised by the performance of these verticals. In many instances, questions were asked regarding the minimum number and length of radials required for efficient operation of ground-mounted verticals. As was noted in previous articles,[12] the answer depends to some extent on the conductivity of the soil at the respective locations. Poorer soils not only require more radials, but ones that are also considerably longer. Although more experimental work is required in this area, it appears that about 50 radials, 0.2 wavelength long, should generally give good operation. The loss in this case will be approximately 1 to 2 ohms. Doubling the number to 100 radials should reduce the loss to less than 1 ohm. It should be noted that even 1 to 2 ohms of loss are appreciable with these short antennas since their radiation resistances are only 12-1/2 ohms.

Again, the author would like to acknowledge the help, encouragement, and interest shown by the many amateurs during our experimental studies on verticals. Very few antenna laboratories can boast of a greater number of willing and competent field stations. In particular, we would like to thank Al Jones, W2GO, for his considerable help in obtaining comparative reports in Australia and New Zealand. This material was originally presented in *QST* by J. Sevick, W2FMI.

References

[1] Sevick, "The W2FMI Ground-Mounted Short Vertical," *QST*, March 1973. Also appears elsewhere in this chapter.

[2] Sevick, "The W2FMI 20-Meter Vertical Beam," *QST*, June 1972.

[3] See footnote 1.

[4] Commercial unit.

[5] See footnote 1.

[6] Cadillac Plastic and Chemical Co., P. O. Box 810, Detroit, MI 48232

[7] Construction details on the top hat are also given in the reference in footnote 1.

[8] 2-1/2-inch (64-mm) diameter, 6 tpi, no. 12 wire.

[9] The characterization and design of these trap verticals will be published later.

[10] See footnote 1 for details on the 40-meter vertical.

[11] See footnote 1.

[12] See footnote 1.

A Multiband Vertical Radiator

An efficient multiband radiator with no traps and no loading coils? Impossible; you can't build one without them and have it work! "Oh, yes, sure you can." I doubt it. "You wanna bet? Come on, I'll show you."

What would you say if the author told you this vertical antenna system was 89-percent efficient but had only six radials? (Efficiency is defined as the ratio of radiated power to total power delivered to the antenna.) No, it's no joke. The vertical antenna that is described here is designed to work against ground systems that are less than optimum.

By increasing the radiation resistance by about 200 ohms, we have been able to improve the effectiveness substantially of a vertical radiator with a poor ground system. The value of 200 ohms was selected as the feed-point radiation resistance because a toroid autotransformer with a 1:4 ratio will match 50-ohm coax line very nicely. An added bonus when using such an arrangement is the Faraday screen effect that reduces noise pickup from being transferred to the feed line. The noise reduction over a conventional network was determined to be about 6 dB. See Figs. 11 and 12.

The system is based on a 135-degree antenna height. The radiation resistance at the base of the structure is about 200 ohms,[1] ideal for our matching system. And at the same time the radiation pattern retains a reasonable form. The 10-meter groundplane on top of the structure acts as a top hat. On 7 MHz the phase loops cause the antenna to look like a fat radiator and between the two, top hat and phase loops, the electrical height of the antenna is raised to within the tuning range of the toriodal loading network. On 14 and 21 MHz the phase loops keep the instantaneous current on the structure in phase and eliminate high-angle lobes. When the system is switched to operate on 28 MHz, the groundplane at the top of the structure is fed through the coax line running up the lower portion of the structure.

Construction and Tuning

The photographs and the drawings show how the antenna is constructed. The system was designed so that "storebought" items could be used for the assembly, rather than fabrication of the antenna components. A list of required parts is given in Table 2.

The tuning adjustments of the system are very noncritical. Tuning can be done with an SWR indicator. The best sequence is to start with the highest frequency and work down. The 28-MHz groundplane used as a top hat can be adjusted before it is attached to the rest of the antenna. The Radio Shack 11-meter groundplane that we used comes with a hairpin or "beta" match. With a short length of 50-ohm coax for the feed line, the groundplane should be adjusted for the lowest SWR in the 10-meter band. After the groundplane has been adjusted and attached to the top of the antenna, the entire system can be raised into position for final tune-up on the lower frequencies.

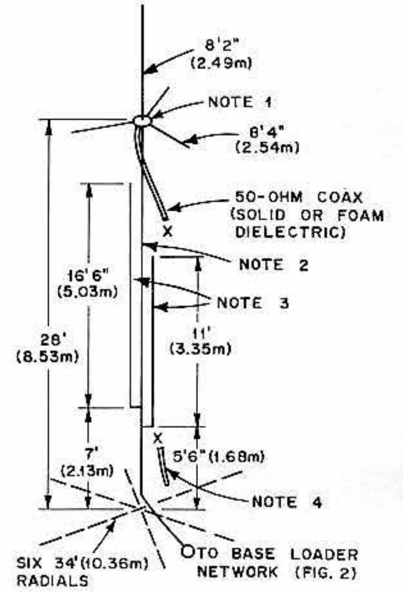
At this point the SWR indicator should be inserted in the 50-ohm feed line from the transmitter, as close to the antenna matching network at the base of the structure as possible. All that remains is the adjustment of the 200-pF capacitor. The

This multiband radiator, just over 36 feet (10.97 m) tall, operates on five amateur bands, 80 through 10 meters.

Table 2

Parts Required for the Multiband Vertical Radiator

3 —10-ft (3.05 m) lengths TV mast; Radio Shack 15-5066.
1 —27-MHz ground plane; Radio Shack 21-901.
3 —100-ft (30.48 m) rolls of 22-gauge hook-up wire; Radio Shack 278-1295.
1 —Amidon Balun kit (see Fig. 12).
1 —Aluminum box for tuner.
1 —28-ft (8.53 m) length of RG-8/U coax line.
4 —8-ft (2.44 m) sections of aluminum tubing (see Fig. 11).
1 —Base insulator; soft drink or (?) bottle.
1 —200-pF capacitor, air variable, surplus.
Misc. — See text and figures.



Notes

1) Radio Shack 27-MHz groundplane cut to dimensions shown. Radials are at right angle and connected to mast.
2) Three heavy-duty 10-ft (3.05-m) sections TV mast.
3) Phase loops, sections of telescoping 5/8-(16-mm) and 1/2-inch (13-mm) aluminum tubing spaced 4-1/2 inches (114 mm) from mast. See text.
4) 50-ohm coax such as RG-8/U. At upper end connect center conductor to top element, braid to ground-plane elements. Connect lower end to base loader network (Fig 12).

Fig. 11 — Details of the multiband radiating structure. See Table 2 for parts list. It is very important that a uniform spacing be maintained for the phasing loops, which may be supported at the bottom by shelf brackets. To support the upper portions of these loops, the author used homemade wooden spacers, 1/2 X 1 inch (13 X 25 mm), which were soaked in paraffin and held in place by screws passing through the loop tubing and the main radiator tubing. Homemade Plexiglas spacers may also be used.

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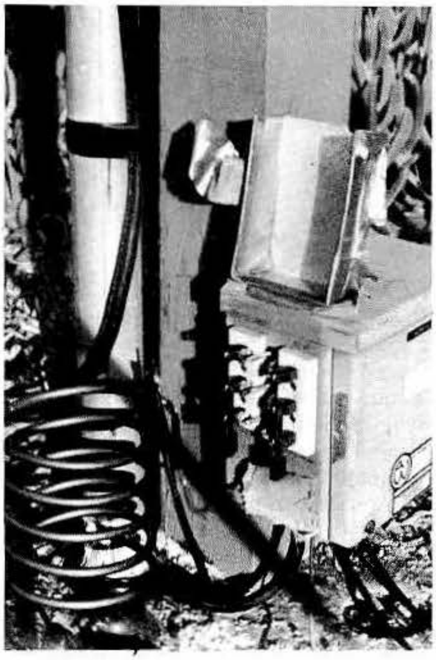
[1] *The ARRL Antenna Book*, 13th Ed. See Fig. 2-74 and the accompanying text on page 60.



The base of the multiband antenna system. The 200-pF capacitor of the matching network is mounted inside a weatherproofed box, and the 80-meter loading coil is mounted outside. The porcelain knife switches for bandswitching are mounted outside the aluminum box under a homemade hinged cover. The structure itself is supported by a 10-foot (3.05-m) wooden post set 2 feet (0.61 m) in the ground (concrete optional).

Although heavy-duty insulators were used to support the radiating mast from the post as shown here, experience has indicated that insulators are not required. The author suggests that a modified pair of chimney-mount brackets be fastened to the post with lag screws. A short length of PVC pipe or Mylar film may be placed around the mast where it is supported, if you feel it necessary to have the mast insulated from the post.

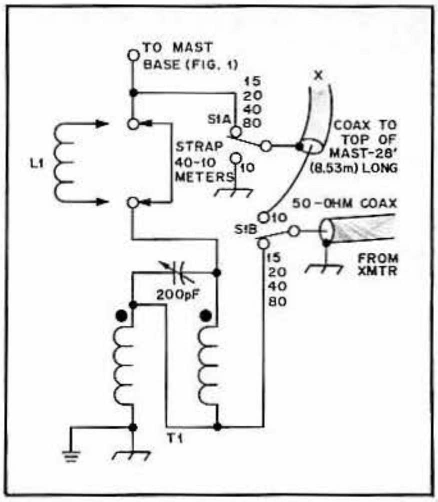


Fig. 12 — Schematic diagram of the base loading network. The connection to the mast base should be made with a short wire, no longer than one foot (0.31-m). The 200-pF capacitor should have a minimum of 1/16-inch (1.6-mm) plate spacing.

L1 — 80-meter loading coil, 0.67 μH; 4 turns of aluminum grounding wire, 3-inch (76-mm) diameter, 1 turn per inch, air core.

S1 — Dpdt, heavy-duty type. Two porcelain knife switches from the local hardware store will suffice, one for each pole.

T1 — Bifilar-wound toroidal autotransformer, 1:4 ratio; 11 turns spaced around 2-inch (51-mm) ID toroidal core: Amidon Balun Kit or equiv. (Amidon Associated, 12033 Otsego St., North Hollywood, CA 91607).

tuning will be different for each band. On 21 MHz the capacitor will be only about five percent meshed, on 14 MHz about half, and on 7 MHz nearly fully meshed. The capacitor on 3.5 MHz, along with the 3.5-MHz coil, can be adjusted to whatever section of the band you wish to work. The bandwidth will be about 400 kHz with less than 2:1 VSWR. To switch bands, all that is required is to set the double-pole, double-throw switch for the proper band and adjust the 200-pF variable capacitor.

All of the antennas constructed so far were cut to the dimensions shown in Fig. 11 and have not required any change. They have been installed in a wide variety of locations and the system design has been broad enough in tolerance to handle all of them. The writer's antenna has been in operation since 1972 and has performed exceptionally well. In the first year on the air, I managed to work 100 countries with less than 250 watts. In several experiments with just the six radials, we made comparative tests between this design and a properly matched quarter-wave vertical over the same radial system. The radiation efficiency was about 60 percent for the quarter wave vs. 89 percent for the "little monster." In the far field the signal improvement was better than 6 dB.

Now there are eight of these antennas on the air, and several more are under construction. All of the hams who have built the antenna have had comparable results to mine.

There are three hams to whom this author would like to give credit. They helped in testing and measuring the system and encouraged me to get it down on paper. They are Bob Crawford, WA6RYZ; Frank Scott, W6WOP and John Campbell, W6NVV. This material was presented originally in *QST* by A. E. Collins, K6VV.

References

The ARRL Antenna Book, ARRL, Newington, CT.

King, *The Theory of Linear Antennas*, Harvard University Press, Cambridge, MA.

Terman, *Radio Engineering*, McGraw-Hill Book Co., New York, NY.

A Triband Vertical Antenna

Keep your vertical antenna simple. Operate three bands without using traps!

The most common vertical is the quarter-wave type, which radiates well and is easily matched to a coax feed line, but has the weakness that it is a single-band antenna. Methods of adapting a vertical for multiband operation include the use of traps, loading coils and elements of different length fed in parallel. The antenna system to be described here was arrived at by treating separately the problems of designing the antenna and of designing the matching system.

The antenna design was easy. A height of 22 feet (6.71 m) is optimum for a vertical antenna for 10, 15 and 20, and several commercial verticals are of this height. It corresponds to about five-eighths wavelength on 10 meters. Greater height results in reduced low-angle radiation on 10, besides being more difficult to erect. A 22-foot (6.71-m) vertical gives better low-angle radiation than a quarter-wave vertical on all three bands and is especially good on 10 meters.

The antenna consists of 22 feet (6.71 m) of 300-ohm twin-lead, with both conductors tied together, held about an inch from a bamboo pole by means of small blocks of insulating material spaced every two feet or so along the pole and held in place with plastic electrical tape. The pole is guyed with nylon fishing line, and the antenna is operated against a groundplane of four quarter-wave radials for each band. The use of twin-lead rather than a single wire simulates a thicker conductor and reduces the impedance, making the antenna easier to match. Even so, the antenna impedances are vastly different on the three bands. The presumed values of impedance are listed in Table 3. These values are taken from published data[1] and assume a cylindrical antenna of specific radius operated against a perfect ground. The antenna is not cylindrical, and it operates against a wire groundplane, so that the impedances listed must be considered approximate only. The results obtained indicate that they are at least fairly close.

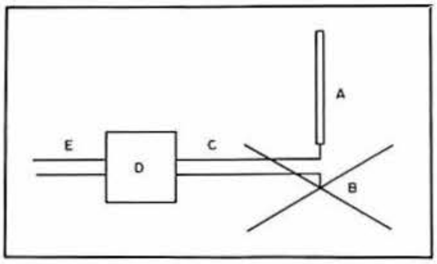


Fig. 13 — The triband vertical antenna system.

A — Vertical radiator, 22 ft (6.71 m) of 300-ohm twin-lead with conductors in parallel.
B — Four radials, each consisting of $1/4\lambda$ of wire, for each band (12 wires in all).
C — Matching section, 27.8 ft (8.47 m) of 300-ohm twin-lead.
D — Reactance unit; see Fig. 14.
E — 75-ohm coax to transmitter, any length.

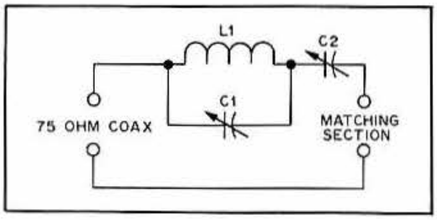


Fig. 14 — Reactance-unit circuit.

L1 — 0.86 μH; 7 turns no. 16 (or heavier). 1-inch (25-mm) dia, 1-inch (25-mm) winding length.
C1 — 30-pF air trimmer set to 23.1 pF.
C2 — 100-pF air trimmer set to 41.7 pF.

Table 3

Approximate impedances at base of 22-foot (6.71-m) ground-plane vertical antenna

Frequency	*Resistance*	*Reactance*
14.250 MHz	100 ohms	+200 ohms
21.375 MHz	1200 ohms	—500 ohms
28.500 MHz	60 ohms	—220 ohms

Table 4

Impedances at input end of 27.8-foot (8.47-m) matching section of 300-ohm twin-lead terminated by the impedances listed in Table 3.

Frequency	*Resistance*	*Reactance*
14.250 MHz	93 ohms	+177 ohms
21.375 MHz	63 ohms	0 ohms
28.500 MHz	75 ohms	—282 ohms

If the three antenna matching impedances are normalized to 300 ohms and plotted on a Smith chart, it can be seen that it is possible to obtain a reasonably good match to a coax line on any of the three bands by using an appropriate length of 300-ohm line as a matching section connected between the antenna and the coax line. What is not possible is to find a single length of line that will provide suitable matching on all three bands.

It turns out, however, that a 27.8-foot (8.47 m) section of 300-ohm line having the 0.82 velocity factor which is usual for twin-lead has interesting characteristics. Such a section of line, connected to an antenna having the impedances listed in Table 3, has the input impedances listed in Table 4. This combination of antenna and matching section is shown in Fig. 13.

It will be noted, first of all, that this combination may be used as it stands on 15 meters and fed with any usual coax. What is even more interesting, however, is that the input resistance is near 75 ohms on all three bands, though on 10 and 20 there is also considerable reactance. If a reactance unit could be made which had just the correct value of reactance to cancel out the input reactance of the matching section on all three bands, the unit could be connected in series with the matching-section input and the system fed with 75-ohm coax on all three bands.

Reactance Units

Can such a unit be made? Certainly! It's not hard at all. It consists of a simple seven-turn coil and two trimmer capacitors and is shown in Fig. 14. The trimmers are most easily adjusted with the aid of a grid-dip meter before the reactance unit is installed. C1 should be set so that L1C1 resonates at 35.85 MHz, and C2 can be subsequently adjusted by temporarily connecting it in parallel with L1C1 and varying it until the combination resonates at 21.37 MHz.

With the reactance unit adjusted as described, the antenna when first assembled showed SWRs of 2.1, 1.4, and 1.5 on 10, 15, and 20 meters respectively. Connecting the unit into the feed system apparently increased its shunt capacitance somewhat, for a small reduction in the value of C1 changed the SWR readings to 1.3, 1.5, and 1.4. These values could probably have been improved still more by further adjustment of C1 and C2, but it was not considered worth the trouble. If it is undertaken it should be borne in mind that the adjustments interact, but that C1 has its greatest effect on 10 meters and C2 on 20 meters. In any case it is not possible to obtain a perfect 1:1 match with this antenna system.

An SWR of 2, however, which can easily be bettered on all three bands, is within the loading capability of almost any transmitter and causes an *additional* loss over a perfectly matched line of less than half a dB even when the transmission line is very long. Since such a change in signal strength is undetectable, an SWR of 2 is in practice as good as an SWR of 1, as far as losses are concerned.

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[1] Jordan, E. C., *Electromagnetic Waves, and Radiating Systems*, Figs. 13-12 and -13, New York: Prentice-Hall, Inc., 1950, pp. 482-3.

A Few Notes

A few observations are in order. The matching section has a fairly high SWR (between 4:1 and 8:1), and it should be spaced well clear of metal objects and should not have sharp bends. TV standoffs are useful here. It is important that the same side of the matching section be connected to the coax shield and to the groundplane. If such a thing were available, 300-ohm coax would probably be preferred for the matching section, but for medium power (180 watts PEP) TV-type twin-lead for the matching section and receiving-type trimmers in the reactance unit have proved satisfactory. The parallel circuit L1C1 does not operate at its resonant frequency, and thus high circulating currents are not encountered. High power might necessitate heavier components. The reactance unit needs protection from the weather and can be built into a small plastic box and sealed with plastic electrical tape.

Although the antenna is matched at three widely separated frequencies, it is not matched at intermediate frequencies and is thus not a broad-band antenna in the usual sense. Nevertheless, it is broad enough for normal ham use. The SWR remains below 2:1 over the entire 15- and 20-meter bands, and also between 28.3 and 29.4 MHz on 10.

All SWRs mentioned in this article have been measured at the transmitter and are thus probably a little optimistic. Transmission-line losses are not known, but the line is not long (about 40 ft. [12.19 m]), and it is doubtful that the SWRs at the reactance unit are much higher than those measured at the transmitter.

This antenna is no match for a quad or a Yagi, but it has provided numerous transatlantic QSOs on all three bands. Because of its effectiveness, convenience, and the cheapness and availability of everything used in its construction, it should appeal to many hams. This material was originally presented in *QST* by Frank A. Regier, OD5CG.

A Multiband Groundplane Vertical Antenna with Tuned Feeders

Who says tuned feeders are used only with horizontal wire antennas? Go multiband with a simple vertical radiator by using a tuned-feeder system — and do it with ease!

For several years, the author has experimented with several versions of this antenna and has found them to be most satisfactory. The antenna shown in Fig. 15 provides not only outstanding performance on 10, 15 and 20 meters, but performance on 40 and 80 meters equivalent to most mobile-antenna installations. Full efficiency on these latter bands can be realized by making the vertical and radial portions proportionately longer.

The antenna system consists of the radiating element, groundplane radials, an open-wire feeder of any convenient length, a Transmatch capable of either series or parallel tuning, and an antenna SWR bridge. This combination is shown in Fig. 16.

Antenna and Radial Lengths

The author preferred to cut the antenna for resonance on one particular ham band (20 meters), but it is not necessary that the antenna be resonant on any band. Efficiency will suffer, of course, on bands where the length is significantly shorter than one-quarter wavelength. Whatever the length chosen for the antenna, the radials should be of about the same length.

Construction

Constructional details are shown in the sketch of Fig. 15. In the event the specified aluminum tubing is not available, thin-walled galvanized electrical conduit, aluminum conduit, or copper pipe may be used.

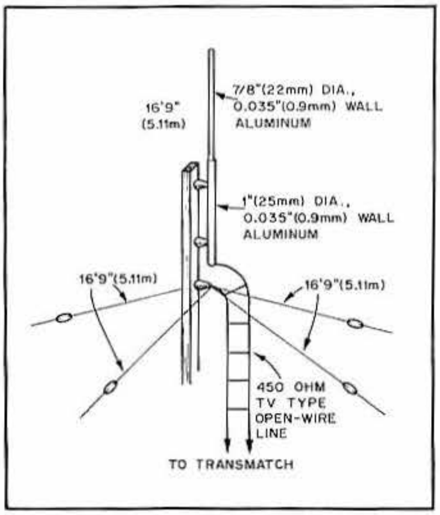

Fig. 15 — Sketch of W4VON's simple multiband antenna.

It is recommended that the vertical element not be supported by drilling holes through the tubing, as this will substantially weaken the structure. An alternative mounting arrangement is shown in Fig. 17. The insulators are porcelain standoff types with a lag-screw insert. They will be found at electrical supply houses (also at Sears), and are sometimes referred to as "saddle" type insulators. The hose clamps are stainless-steel gear type.

Adjustment

Operation of the antenna is simple. The Transmatch (a suitable one, including SWR bridge, is described in the ARRL *Handbooks)* and SWR bridge are connected, and the tuning network adjusted for

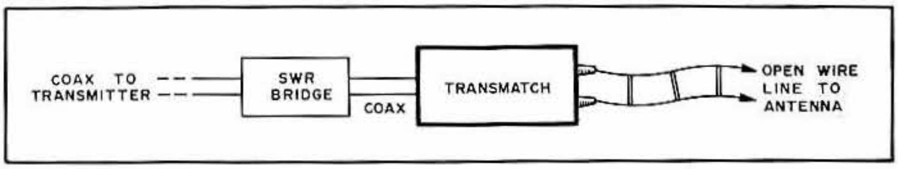

Fig. 16 — Recommended setup for coupling antenna line to low-impedance transmitter output.

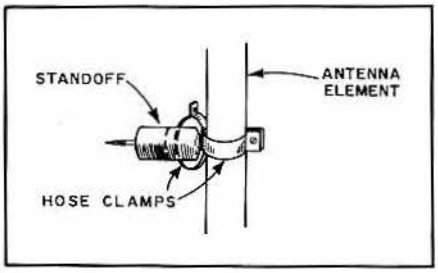

Fig. 17 — Suggested method of mounting radiator element without drilling holes in aluminum tubing.

maximum forward and minimum reflected power. Initially, it will be necessary to determine experimentally whether series or parallel tuning is required for the particular combination of band, feeder length, and antenna length selected.

The tuned-line-fed groundplane vertical antenna gives excellent performance, can be easily constructed in just a few hours even by a beginner, requires a minimum of installation space and costs less than $5, excluding the Transmatch and SWR bridge. The tuned circuit of the Transmatch provides excellent discrimination against harmonic output from the transmitter. Ease of construction and portability make this antenna an ideal one for Field Day use.

In case one wonders about the mismatch between the line and the antenna, the secret is in the use of open-wire line. The loss in such a line with an SWR of 25:1, at 10 meters, is less than the loss in RG-58/U when the latter is matched. This material was originally presented in *QST* by Arthur S. Gillespie, Jr., K4TP.

A Helically Wound Vertical Antenna for the 75-Meter Band

"Around and around she goes, and where she comes out — nobody knows." True, perhaps, with a wheel of fortune, but with a helically wound vertical the rf comes out effectively for DX and local work!

In order to have a full-size vertical antenna for the 75-meter band, the antenna would have to be around 65 feet (19.81 m) tall. That, alone, would require guying, or some other means of support which would result in a structure with no aesthetic appeal to any nonhams (who comprise almost 100 percent of the author's neighborhood). By using a helical configuration, the overall antenna height is reduced, thus eliminating the need for guying. With the helically wound antenna, more equal current and voltage distribution is accomplished (as compared with a lumped impedance from a loading coil). As a result, a better radiation pattern is produced. With this system very little reactance has to be cancelled out, eliminating the need for an overly large "top hat."[1] This antenna will easily take the full legal power limit.

Construction details for the antenna are shown in Fig. 19. The following is a list of parts used in constructing the antenna system.

1 — 20-ft (6.10-m) section of 4-inch (102-mm) OD plastic pipe (obtained at a local plumber)

130 ft. (39.62 m) no. 12 plastic-insulated

The dark pole to the immediate left of the tower is the WA0WHE helically wound vertical antenna.

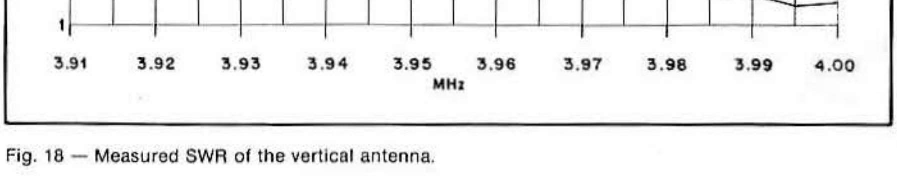

Fig. 18 — Measured SWR of the vertical antenna.

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[1] [Editor's Note: Some form of metal top hat should be connected to the last turn of the driven element at the high-impedance end of the radiator. Extremely high levels of rf voltage can develop at the end of the helix, sometimes causing the tip of the antenna to burn. The top hat tends to lower the Q of the antenna, thus reducing the voltage level at the far end. An aluminum pie tin mounted on a ceramic cone insulator works well in this application.]

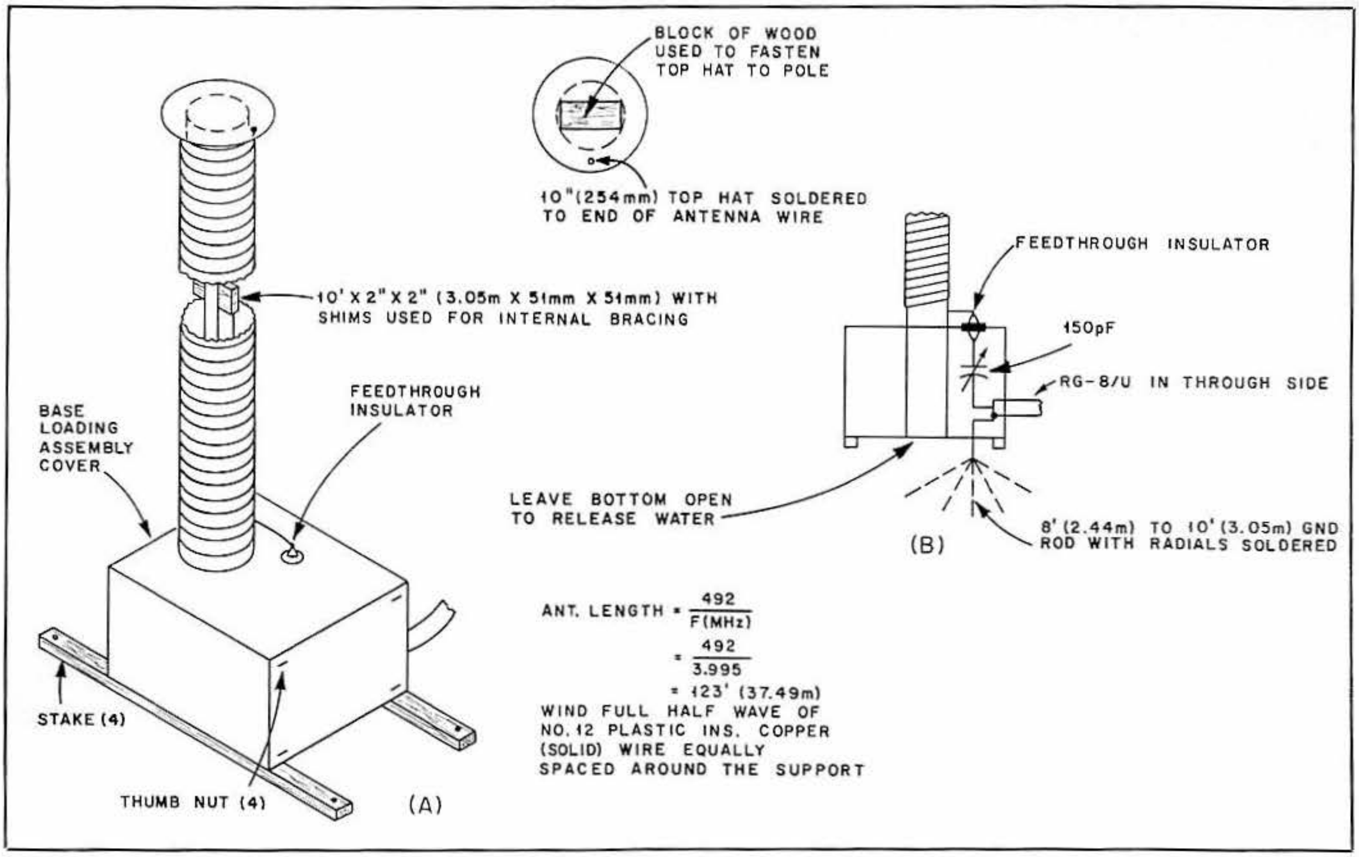

BLOCK OF WOOD USED TO FASTEN TOP HAT TO POLE
10"(254mm) TOP HAT SOLDERED TO END OF ANTENNA WIRE
10' X 2" X 2" (3.05m X 51mm X 51mm) WITH SHIMS USED FOR INTERNAL BRACING
FEEDTHROUGH INSULATOR
BASE LOADING ASSEMBLY COVER
LEAVE BOTTOM OPEN TO RELEASE WATER
STAKE (4)
THUMB NUT (4)
(A)
ANT. LENGTH = 492/F(MHz)
= 492/3.995
= 123' (37.49m)
WIND FULL HALF WAVE OF NO. 12 PLASTIC INS. COPPER (SOLID) WIRE EQUALLY SPACED AROUND THE SUPPORT
FEEDTHROUGH INSULATOR
150pF
RG-8/U IN THROUGH SIDE
8' (2.44m) TO 10' (3.05m) GND ROD WITH RADIALS SOLDERED
(B)

Fig. 19 — Construction details of the helically wound antenna.

solid copper wire (allow a little extra, about 2 ft. [0.61 m])

1 — 10-in. (254-mm) disk of sheet metal (top hat; stop at a sheet metal or furnace repairman — I got this free)

260 ft. (79.25 m) no. 14 solid bare copper wire (I used only four radials in this system; use as many as you have room or money for)

20 sq. ft. (1.86 sq. m) of marine plywood for base

2 — 2 × 2 10-ft. (3.05 m) sections, for internal bracing

1 — 8-ft (2.44-m) copper ground rod (for radial junction)

The cost can be reduced considerably if all materials are readily located or already owned.

Fig. 18 shows the results of SWR measurements. The SWR indicator used to make the measurements was a Midland model. The antenna was adjusted for minimum SWR at resonant frequency with the tuning capacitor at the base. The frequency for this antenna is 3995 kHz with 123 feet (37.49 m) of wire wound on the support and one 8-ft. (2.44-m) ground rod and four 65-ft. (19.81-m) radials. There are numerous configurations possible with this system including a broadcasting favorite such as phasing two or more structures. I forgot to mention . . . give the entire structure one or two coats of marine varnish to seal the turns. This material was originally presented in *QST* by Gary L. Ellingson, WA0WHE.

The Ground-Image Vertical Antenna

The name of the game with vertical antennas is the "ground system." Not just any hastily contrived radial ground will do the job right. Read these details for building an effective ground that provides positive results.

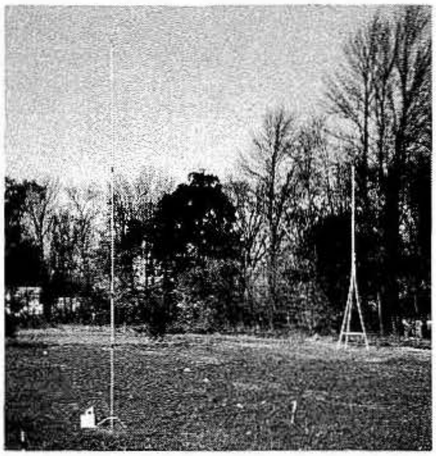
Even though a beam antenna supported at the modest height of 40 feet (12.19 m) is a compromise (a 20-meter beam should be higher to be really effective), it still can be an obstacle to good neighborly relations, at least if your neighbors don't appreciate the ecological beauty of such an installation. Moreover, even that modest sort of an installation presents quite a number of engineering problems.

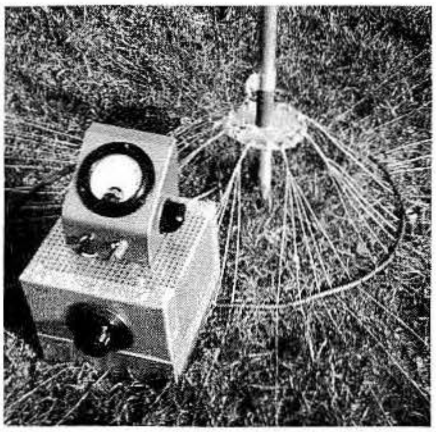
This report presents the results of the first phase of an investigation to find a less conspicuous but equally effective antenna for use at a new location. The author hopes it will provide suggestions for those faced with a similar problem. At the least, it may be of some value to those with a general interest in the subject of antennas.

This first part of this section deals briefly with theoretical considerations, the second with experimental results on quarter-wavelength and five-eighths-wavelength verticals, and the third on the test equipment. It should be pointed out at the outset that the information presented here is the work of a hobby and as such cannot be exhaustive. It is hoped that others will repeat some of the experiments, extend the work, and report the effect in practice of a groundplane system above 3 MHz. To my knowledge such practical data have not been reported.

Theoretical Considerations

A beam antenna possesses the advantage of gain and directivity. Nevertheless, its DX capability is determined primarily by its vertical radiation pattern. A large portion of the radiated energy should be directed between 5 and 25 degrees from the horizon.[1,2] Horizontally polarized antennas yield lower angles of radiation with increase in height above the ground. This is a result of the interference pattern created by reradiation from the earth's surface. Since the earth is a somewhat conducting medium, the electric field tangential to the surface must be approximately zero. This "boundary" condition is brought about by the induced surface currents which create an electric field of opposite phase. This field then combines constructively and destructively with the initial radiation from the antenna. A model for this condition is an image antenna of opposite phase below the earth's surface as a depth equivalent to the height above the surface.[3] In order to get a lobe below 15 degrees, the antenna height must exceed a wavelength. This is greater than 60 feet (18.29 m) on 20 meters.


The 20-meter vertical antenna in the foreground, and the 26-foot (7.93-m) test tower.


The base of the vertical element of the antenna and the impedance bridge. Forty radials, in bundles of five are fastened to the aluminum base plate and are tied down with a ring made from copper tubing.

On the other hand, a vertical antenna, in the ideal case, possesses an image which is in phase to produce a lobe tangential to the earth's surface. Only when the antenna length is increased to a wavelength, or multiple thereof, does the tangential lobe disappear. This is true whether the antenna is on the ground or suspended in space. Therefore, a vertical beam, i.e., an array of vertical antennas coupled together with an appropriate feed system, on the surface of the earth, seemed to be the logical choice for the new installation since it would appear to meet the following objectives: The system should

1) Exhibit a minimum profile.
2) Be easy to install and tune.
3) Offer a low angle of radiation.
4) Not require a large outlay of money.

The author proceeded, therefore, to construct an array with four vertical elements. When the tests were begun, it immediately became apparent that the simple procedures the writer was using were inadequate to cope with such a complex system. The author had to start anew to develop a test procedure and to build some suitable test equipment. The logical step was to backtrack to a single vertical antenna and use it as a standard on which to develop some basic test standards. As discussed subsequently, the writer found that relatively simple equipment, e.g., a simple impedance bridge, a field-strength meter, and a test oscillator, gave this author all of the data about the system that he needed.

It is important to note that a true ground-image antenna differs substantially from a ground-plane antenna system which relies merely on a few $\lambda/4$ radials above the ground. A true ground-image system results when a sufficient number of radials are used and an image of only the vertical section is sufficient to describe it. Considerable information[4,5] is available on ground-image systems for verticals operating below 3 MHz. The results have shown that some

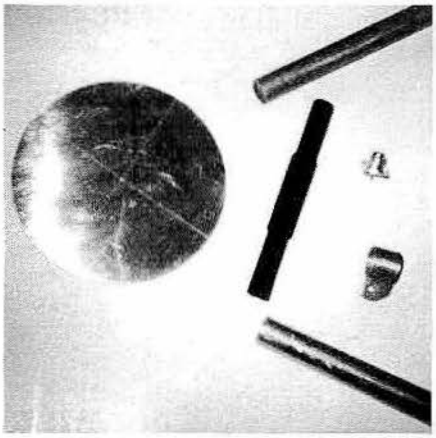
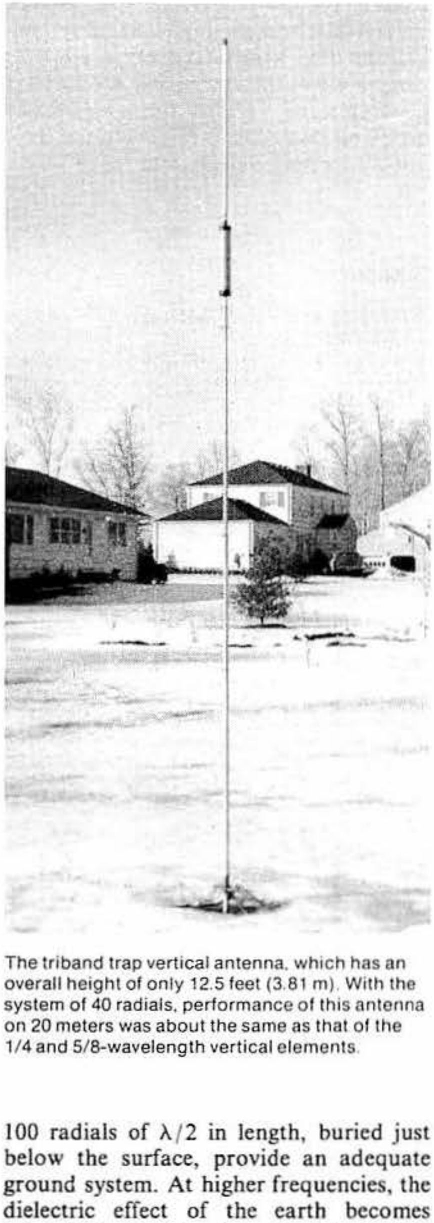

Base hardware for the antennas being tested. The insulator was made from 1-inch (25-mm) maple dowel, turned down to accept the 7/8-inch (22-mm) inside diameter of the ground and antenna tubing.

Table 5

Comparison of responses of 1/4-wavelength and 5/8-wavelength vertical antennas at low radiation angles. Data were taken by field-strength meter mounted on a wooden tower at a distance of 7.5 wavelengths at 14.25 MHz. Field strength (E) is normalized to maximum value obtained with 5/8-wavelength case.

θ	E(λ/4)	E(5/8λ)	GAIN OF 5/8-λ ANTENNA
0.1°	0	0.58	∞
0.4°	0	0.62	∞
0.75°	0.62	0.80	3.4 dB
1.1°	0.69	1.0	3.2 dB
1.5°	0.62	0.92	3.4 dB
2.25°	0.48	0.80	4.3 dB
3°	0.41	0.69	4.5 dB



The triband trap vertical antenna, which has an overall height of only 12.5 feet (3.81 m). With the system of 40 radials, performance of this antenna on 20 meters was about the same as that of the 1/4 and 5/8-wavelength vertical elements.

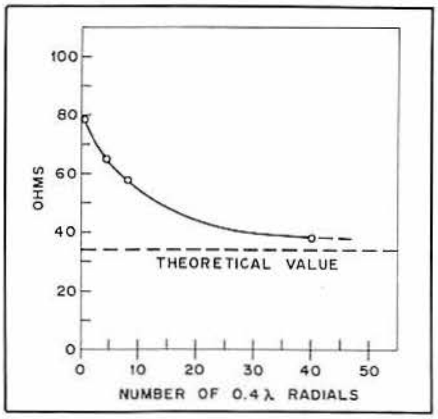


Fig. 20 — The input impedance of a 20-meter quarter-wave vertical antenna as a function of the number of radials 0.4-wavelength long. The four and eight radials consisted of bundles of five wires of no. 18 guage. The 40-radial point was obtained by fanning out the eight bundles.

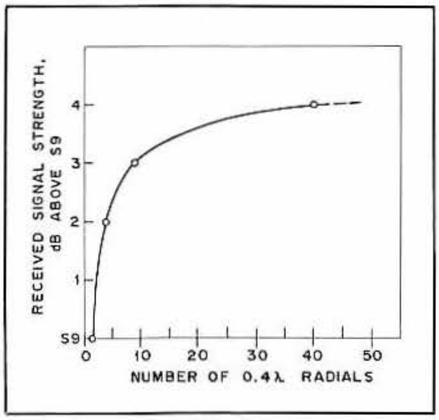


Fig. 21 — The improvement of low-angle radiation of a quarter-wavelength vertical antenna on 20 meters as a function of the number of added radials. A test oscillator was mounted on a wooden tower four wavelengths away at an elevation angle of six degrees from the base of the vertical.

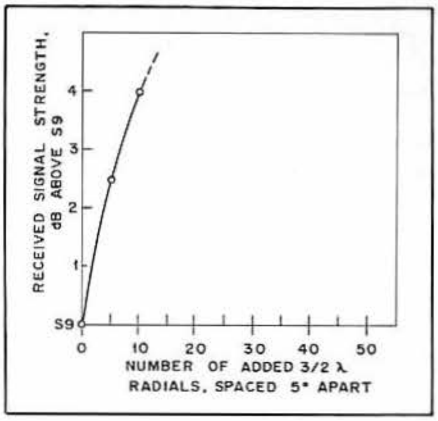


Fig. 22 — The result of interlacing 3/2-wavelength radials in a particular direction. Data were obtained by using a test oscillator on a wooden tower eight wavelengths away, at an elevation angle of 3 degrees from the base of the vertical. The results indicate the advantage of longer wires and the possibility of directional properties of a nonsymmetrical radial system.

100 radials of λ/2 in length, buried just below the surface, provide an adequate ground system. At higher frequencies, the dielectric effect of the earth becomes important, resulting in severe discrimination of radiation or reception at very low angles.[6,7] At low angles, the waves not only suffer by absorption, but also by a change in phase which results in destructive interference. Since little specific information was available at higher frequencies, the objective of the present work was to measure the input impedance and vertical radiation pattern at low angles of a vertical antenna as a function of the number of radials, in order to determine the feasibility of a vertical-array system as a competitor to beams at high elevation. The results of the tests were most gratifying. The author found that many of the "rules of thumb" which have developed and have been perpetuated to the point where they are practically taken for granted were more myth than truth.

Experimental Results

The classical paper on radial systems, which reports experimental results at 1 and 3 MHz, indicates that a large number of radials 0.4λ long should be used.[8] This appeared to be a good starting point for a 20-meter vertical. Accordingly, to check the number of radials needed, this author used eight bundles of wires, each 25 feet (7.62 m) long, and each made up of five no. 18 copper wires. Each bundle was bolted to a 5 × 1/4-inch (127 × 6-mm) aluminum plate as shown in the photograph. The writer was then able to use each bundle as a radial, measure the input impedance of the system, and then separate the bundles, wire by wire, to increase the number of radials in the system.

Fig. 20 shows the input impedance as a function of the number of radials used. Measurements were made with a simple impedance bridge. (Its construction is discussed later.) The antenna was resonated before each measurement was made, and the difference between the 40-radial system and the 8-radial system resulted only by fanning out the bundles of wires. This technique points out another important feature of ground systems and refutes one of the old myths: since the current carried by the radial system is equally divided among n radial elements, each radial is required to carry only 1/n of the total current. This means that relatively small diameter wire is perfectly adequate.

Moreover, it was found that at the higher frequencies it is best to keep the radials near the surface of the ground. Radials buried more than a few feet become less effective! Thus, you should not rely on the old admonition that radials should be 6 feet (1.83 m) down to be effective. This writer found that burying the wires slightly below the surface is the best way of installing the system. Mechanically the radials can be nailed down, electrically they are most effective, and esthetically they provide little interference to a healthy stand of grass.

It will be seen from Fig. 20 that the input impedance for a vertical antenna is drastically affected by the number of radials. Many radial wires are necessary to prevent an excessive loss of power and to provide a convenient input impedance. Fig. 20 also shows the theoretical impedance limit for an antenna having an effective height-to-radius ratio of 300:1.[9]

Fig. 21 shows the effect on low-angle radiation as a function of the number of radials. These data were obtained by placing a test oscillator on a wooden tower, four wavelengths away. A photograph shows the 20-meter vertical and the 26-foot wooden test tower.

The effect of using longer radials in a particular direction is shown in Fig. 22. Radials of no. 18 wire, 3/2 wavelengths long, were put down between the existing 40 radials. The spacing between the longer wires was five degrees. The considerable improvement indicates the need for longer wires and the directional properties a groundplane could give.

A 5/8-wavelength vertical was also constructed and tested. It consisted of a 40-ft. (12.19-m) telescoping aluminum pole and a loading coil of eight turns of no. 12 wire with a diameter of 2.5 inches (64 mm). The comparison in low-angle radiation at a distance of 7.5 wavelengths is presented in Table 5. A field-strength meter was mounted at different heights on the 26-foot (7.93-m) tower. The groundplane for these data consisted of the 40 0.4-λ radials plus the 11 3/2-λ ones. Measurements were taken in the direction of the added longer radials. The results show the improvement in low angle radiation offered by the 5/8-λ vertical. The input impedance of this longer antenna was found to be 76 ohms.

On-the-Air Checks

From these experiments and measurements the author decided to settle on a 1/4-λ antenna with approximately 40 radials. The installation is shown in the photograph. This writer then proceeded to make on-the-air tests to compare its effectiveness with an inverted-V antenna having its apex at 0.4 wavelength, and with a 5/8-λ vertical using the same ground system. Surprisingly, the 1/4-λ vertical seemed to perform just as well as the much taller 5/8-λ vertical. This could result from the fact that most signals arrive after several hops and the optimum lobe angle is probably as high as 15 to 20 degrees.[10] At that angle, the λ/4 antenna actually enjoys an advantage. With practically all DX contacts, the verticals had a 6- to 8-dB improvement over the inverted V! The only exceptions were at intermediate distances and for local contacts. At about 500 or 600 miles, the inverted V with its higher angle of radiation gave better results. Locally, the verticals gave far superior performance. Improvements of 10 to 15 dB were recorded. A triband trap vertical antenna was also tested on 20 meters and found to be practically the same in impedance and performance. This antenna had an overall height of only 12.5 feet (3.81 m)!

Test Equipment

A most interesting aspect of antenna measurements is that the equipment can be rather simple and in many cases constructed from items most amateurs have in their junk boxes. All that is really needed is some standard to compare with, such as a wattmeter or an S meter that is known to have reasonable accuracy. This writer has used both — the wattmeter in a Drake L-4B linear amplifier and the S meter in a R-4B receiver.

The impedance bridge shown in the photograph was patterned after the one shown in the *ARRL Handbook*. Care was taken in shielding the input and output circuits. The meter was mounted externally in order to minimize stray pickup. A calibration curve was obtained at 14.25 MHz by using many carbon resistors of known values as the load.

The field-strength meter is a simple diode detector and dc amplifier. The instrument was constructed to cover the 10-, 15- and 20-meter bands. Its meter was also mounted externally, The antenna length for the field-strength meter was determined by the strength of the available field. In addition to these pieces of test equipment, a 20-meter transistorized crystal oscillator was used for many of the tests.

Conclusion

The performance of a vertical antenna on the ground is highly dependent upon a good ground system, and, properly installed, the antenna can be a very good performer indeed for DX and local contacts. This is particularly true at the higher frequencies where the dielectric property of the earth plays a major role. Forty radials of no. 18 wire, 0.4λ long, will increase the total radiated power by about 3 dB. Radials can be thin if a sufficient number are used. The thought of using thick wires buried deeply, probably a carryover from lightning grounds, is not valid at higher frequencies. The idea of using only four buried radials, as commonly recommended, is a serious error, and if this article does nothing more than eliminate that misconception, this author will be satisfied. Since the electric field only penetrates the ground for a foot or two at the higher frequencies, the radial wires need be buried only as deep as necessary to escape children's feet and the lawn mower. Finally, these results from the single vertical antenna indicate that a vertical array could be a competitor to the more elaborate horizontal beams and warrants further investigation. This material was originally presented in *QST* by Jerry Sevick, W2FMI.

References

[1] Terman, *Radio Engineering*, McGraw-Hill, New York, 1947, p. 651.

[2] Friis, Feldman, and Sharpless, "The Determination of the Direction of Arrival of Short Radio Waves," *Proceedings of the IRE*, Vol. 22, No. 1, January 1934.

[3] Williams, "Antenna Theory and Design," *The Electrical Design of Antennae*, Vol. 2, Second Edition, Sir Isaac Pitman and Sons Ltd., London, p. 126.

[4] Brown, Lewis, and Epstein, "Ground Systems as a Factor in Antenna Efficiency," *Proceedings of the IRE*, Vol. 25, No. 6, June 1937.

[5] Wait, "Input Resistance of L. F. Unipole Aerials," *Wireless Engineer*, May 1955.

[6] Feldman, "The Optical Behavior of the Ground for Short Radio Waves," *Proceedings of the IRE*, Vol. 21, No. 6, June 1933.

[7] Jager, "Effect of the Earth's Surface on Antenna Patterns in the Short Wave Range," *Internat Elekitron Rundschau 1970*, Nr. 4.

[8] See footnote 4.

[9] King and Harrison, "The Impedance of Short, Long, and Capacitively Loaded Antennas with a Critical Discussion of the Antenna Problem," *Journal of Applied Physics*, Vol. 15, February 1944.

[10] See footnote 2.

The W2FMI Ground-Mounted Short Vertical

Just because the vertical is physically short doesn't mean it won't provide excellent results in DX work. Theory says it can be done. Here's how!

A short vertical antenna, properly designed and installed, approaches the efficiency of a full-size resonant quarter-wave antenna. Even a six-foot (1.83 m) vertical on 40 meters can produce an exceptional signal. Theory tells us that this should be possible, but the practical achievement of such a result requires an understanding of the problems of ground losses, loading, and impedance matching. This paper covers design principles which are applicable to all of our amateur bands.

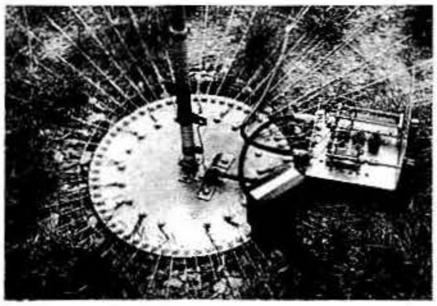
Background

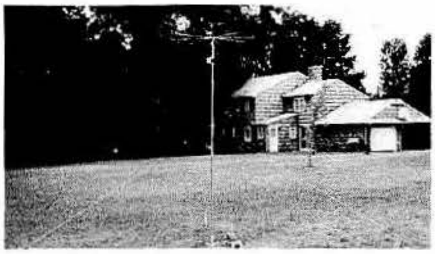
Earlier work by the author[1] on the radiation efficiency of a ground-mounted vertical resulted from the desire to design a simple, inexpensive, low-profile DX beam for 20 meters. This first work reviewed the theoretical considerations involved and pointed out that a good ground system is essential to achieve efficient operation of a resonant quarter-wave antenna. The second work applied these results to a 20-meter beam.[2] In the process of trying to extend the results of these investigations to the 40-, 80- and 160-meter bands, and to possible multiband operation, the need arose to understand the operation of a shortened vertical and the effects of different loading schemes on the input impedance.

The first part of this paper deals with the theoretical considerations of a short vertical antenna and the experimental procedures involved in measuring the various parameters. This is followed by experimental results which show the trade-offs involved in shortening antennas by various loading schemes. Finally, specific designs are given for the 40- and 80-meter bands.

Theoretical and Experimental Considerations

There are several old familiar axioms in Amateur Radio that are not completely understood by the amateur. The author refers specifically to the two sayings: *Make the antenna as long as possible and erect it as high as possible,* and, *A full-size beam is better than a smaller beam, and a tall vertical is always better than a short one.* The first axiom is particularly relevant to horizontal antennas, where height is most important for reliable DX operation.[3] Increasing the length tends to increase the gain in certain directions. But with the vertical antenna, taking it off the ground and feeding it at a voltage point (like the J antenna) in order to eliminate radials can result in poorer performance because of increased earth loss.[4,5] More experimental work remains to be done on this phase of vertical antennas. The second axiom noted above is generally true, but misinterpreted by many. The author refers to those important properties: power gain — important in transmitting and capture cross-section — important in receiving. (Power gain is the gain, in magnitude, compared to an isotropic radiator; cross-section is a fictitious area related to the ability of the antenna to intercept the radiated power and make it available to the receiver for detection.) As will be seen below, very little is compromised in these properties by shortening the antenna.


The matching network and base hardware showing 115 radials with the 6-foot (1.83-m) vertical. The pi network is covered with a plastic bag.


The 10-foot (3.05-m), 40-meter vertical designed for an input impedance of 12.5 ohms in order to use a 4:1 step-up bifilar transformer. The top hat has a diameter of 4 feet (1.22 m) and the coil, placed one foot (0.31 m) below, has 14 turns. Shown at the base is the transformer and impedance bridge.

The author with the 6-foot (1.83-m), 40-meter vertical.

The short antenna has been defined as one that is small compared to a wavelength. In a more exact form, it is defined in such a manner as to simplify the mathematics in the theoretical calculations. King[6] has used the following inequality as the definition where

$$\beta_0 h = \leq 0.5$$

$$\beta_0 = \frac{2\pi}{\lambda}$$

h = half-length of a center-fed antenna or the height of a ground-mounted vertical.

λ = the wavelength

$\beta_0 h$ is actually a quantity which is used to express the height of an antenna in terms of an angle in radians. Thus, this quantity is independent of the frequency. Since 40

Table 6

Inductive Loading

	No. of Turns*	h	$R_{rad.}$
1) *Base Loading*			
a)	7	24 ft 3 in.	14.5 ohms
b)	10	18 ft 9 in.	7.5 ohms
c)	12	15 ft 7 in.	5.5 ohms
d)	14	13 ft	4 ohms
e)	18	8 ft 10 in.	2 ohms
2) *Midpoint Loading*			
a)	6	28 ft 5 in.	28.5 ohms
b)	11	24 ft 3 in.	25.2 ohms
c)	15	19 ft 8 in.	16.5 ohms
d)	18	15 ft 8 in.	12.3 ohms
e)	24	14 ft 6 in.	10.5 ohms
3) *Three-Quarter Point Loading*			
a)	10	29 ft 4 in.	32.5 ohms
b)	18	23 ft	26 ohms
c)	23	21 ft 2 in.	23.5 ohms
d)	24	19 ft 2 in.	22 ohms

*B & W 3029, 2-1/2 in. dia, 6 TPI, no. 12 wire.

1 ft = 0.3048 m

Table 7

Top Hat and Distributed Loading

1) *Top Hat Loading* (4-spoked wheel with 1/8-inch Al wire rim)

	Diameter	*h*	*$R_{rad.}$*
a)	1 ft	30 ft 10 in.	34 ohms
b)	2 ft	28 ft 7 in.	32.5 ohms
c)	4 ft	24 ft	30 ohms
d)	7 ft	19 ft 2 in.	23.5 ohms
e)	4 ft*	23 ft 4 in.	29.4 ohms

2) *Distributed Loading* (Helical Antenna)

	No. of Turns	*h*	*$R_{rad.}$*	*Top Hat at 1.5 ft Above Coil*
a)	111	12 ft	8 ohms	1 ft dia.
b)	105	12 ft	10 ohms	2 ft dia.
c)	113	7 ft	6 ohms	2 ft dia.
d)	75	7 ft	7.5 ohms	4 ft dia.

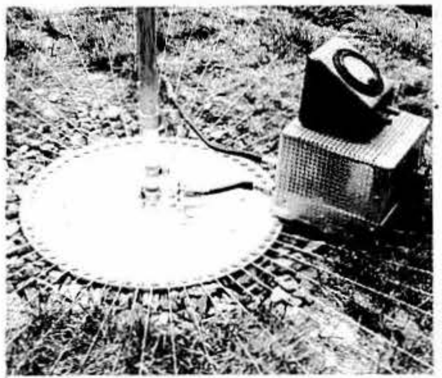
*8-spoked wheel
1 ft = 0.3048 m

Table 8

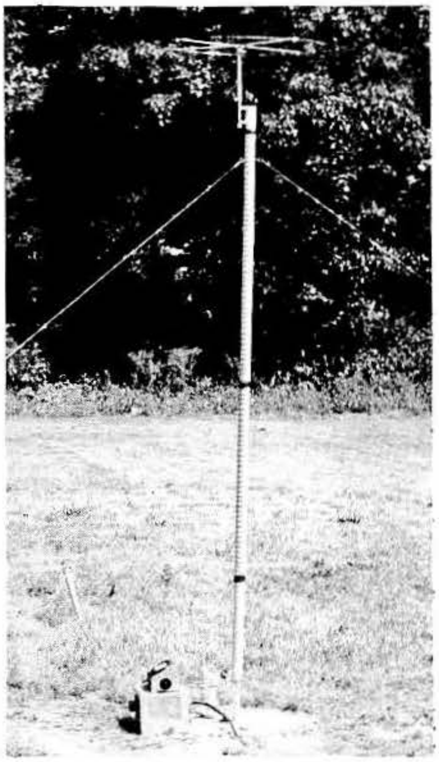
Parameters of the 40-Meter Short Vertical Designs

Total Height	*$R_{rad.}$* (ohms)	*No. Turns**	*Dia. Top* (ft)	*Bandwidth*
6 ft	3.5	14	7	100 kHz
8-1/2 ft	7.5	at 6 in. below top hat		
8-1/2 ft	7.5	75 on 7 ft dowel 1-5/8 in. in dia.	4	100 kHz
10 ft	12.5	14 1 ft below top hat	4	125 kHz
15 ft 10 in.	12.5	7 at base	4	540 kHz

*Except for helical antenna, coil wire is same as shown in Table 6.
1 ft = 0.3048 m



Base of the vertical antenna with 60 radials. The aluminum disk is 15 inches (0.38 m) in diameter and 1/4 inch (6 mm) thick. Sixty tapped holes for 1/4-20 aluminum hex-head bolts form the outer ring and 20 form the inner ring. The insulator is polystyrene material with a 1-inch (25-mm) diameter. Also shown is the impedance bridge for measuring input resistance.
Originally, circular wires were used to connect all radials together. These were positioned every 2 feet (0.61 m), starting from the antenna base. Then, one at a time, they were removed, meanwhile keeping a check on the antenna radiation resistance. There was no apparent change in the radiation resistance, so it was concluded that the interconnecting rings of wire were not needed in the ground system.



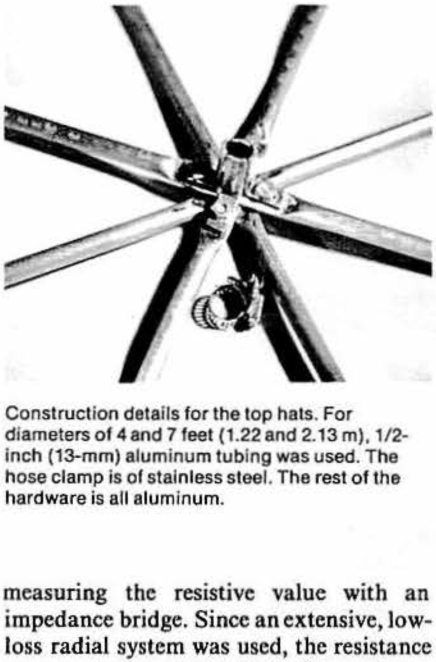
Eight-and-one-half-foot (2.59-m) helical antenna using a 2-foot (0.61-m) top hat 1-1/2 feet (0.46 m) above the 7-foot (2.13-m) helix. The 75 turns have approximately a 3-inch (76-mm) pitch below the midpoint and 1.5-inch (38-mm) pitch above. Very little difference was noted in reversing the pitches. The input impedance was 7.5 ohms.

meters was used mostly for experimental results presented in this article, the inequality above assures accurate theoretical calculations for verticals of 11 feet (3.35 m) or less.

The theoretical results show that the power gain for a *very* short antenna, even less than 1-foot (0.31-m) high on 40 meters, is 1.5.[7] This increases slowly to 1.513 for an 11-foot (3.35-m) antenna. These gains are to be compared to about 1.62 for a resonant quarter-wave vertical. It can be seen that this difference amounts to less than 0.4 dB or 0.07 S unit, based on 6 dB per S unit.

In a similar fashion, the capture cross-sections differ by relatively small amounts. For the *very* short antenna, a cross-section value is $0.119\ \lambda^2$, while for the quarter-wave vertical it is $0.13\ \lambda^2$. This is surprising to many since it is difficult to visualize a vertical of a foot or two (0.31 or 0.61 m) in height on 40 meters, having practically the same receiving ability as a 33-foot (10.06-m) quarter-wave antenna!

But the important property of a short vertical that makes its capture cross-section nearly the equivalent of a full 1/4-λ antenna is its *very small value of input resistance.* Fig 23 shows the theoretical curve and the 40-meter experimental results for the input resistance of a ground-mounted vertical as a function of height.[8] The experimental data were obtained by essentially canceling out the capacitive reactance of the vertical by an inductance at the base of the antenna and measuring the resistive value with an impedance bridge. Since an extensive, low-loss radial system was used, the resistance measured was actually that of the antenna itself, which is called the *radiation resistance.*



Construction details for the top hats. For diameters of 4 and 7 feet (1.22 and 2.13 m), 1/2-inch (13-mm) aluminum tubing was used. The hose clamp is of stainless steel. The rest of the hardware is all aluminum.

Fig. 24 shows the input resistance of a quarter-wave resonant vertical as a function of the number of radials. At the 115-radial point, the input resistance approaches the theoretical value of 35 ohms, which strongly indicates low earth loss and, hence, reliable data in short antenna measurements. The picture also shows the base hardware for 60 radials. The wire is 15-gauge aluminum. There is nothing sacred about 15 gauge. No. 22 wire, or even no. 28, would be just as good.

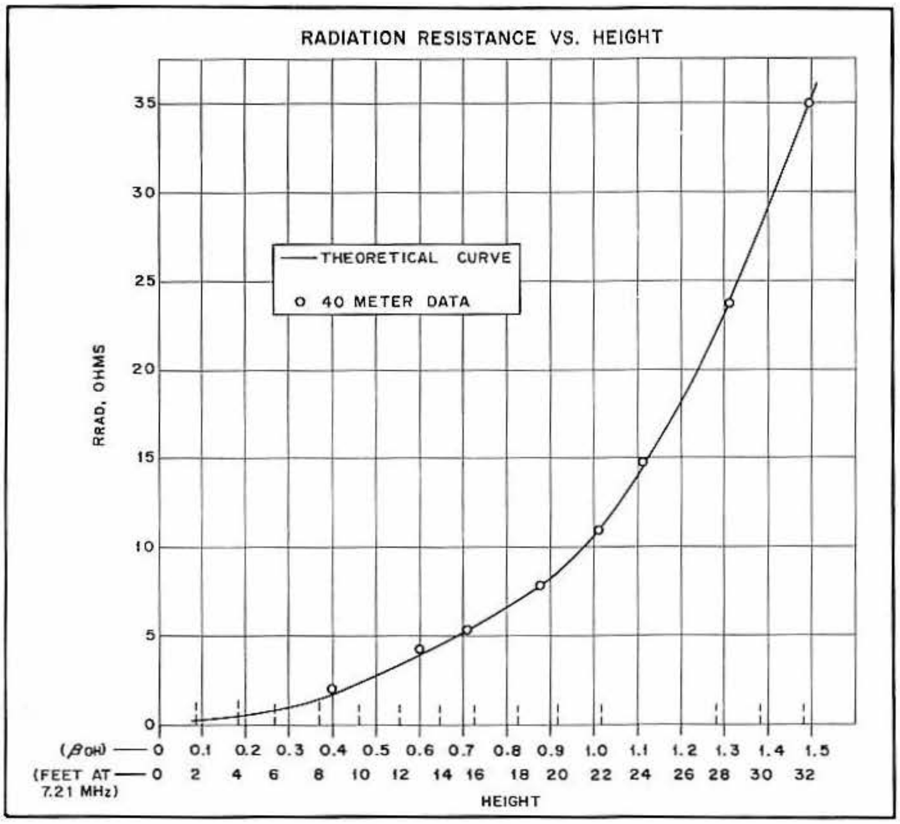


Fig. 23 — Theoretical curve and experimental results for the radiation resistance as function of height.

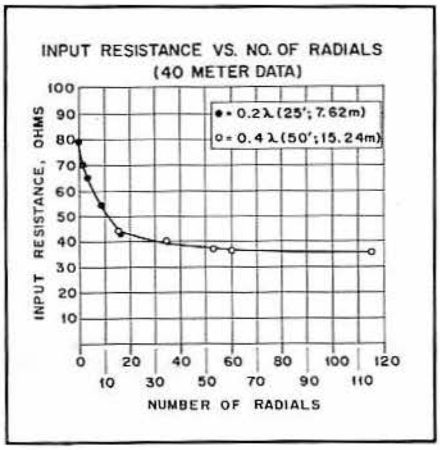


Fig. 24 — Input resistance of a quarter-wave ground-mounted resonant vertical as a function of the number of radials.

It should also be noted that very little difference was noted whether 0.2-λ or 0.4-λ radials were used. At 16 radials, the results are practically identical. In fact, this curve is also similar to the one obtained on 20 meters which was reported earlier.[9] More work remains to be done on the trade-offs in performance versus length of radials for ground-mounted verticals.[10]

Experimental Results

In designing a shortened vertical beam for 40, 80 or 160 meters, a most important consideration is the value of the input impedance of the driven element. As seen in Fig. 23, a shortened vertical using base loading has an extremely low value, particularly at one-eighth wavelength and less. This input impedance is then usually lowered in the presence of other elements in a beam array. The resulting very low value of input impedance makes it difficult to design matching networks. Therefore, an experimental investigation was undertaken to see what increases in radiation resistance could be obtained by other methods of loading, i.e., top hat, three-quarter point, midpoint, and distributed (helical antenna). The results of these experiments are shown in Fig. 25. Table 6 shows the individual points for inductive loading and Table 7 for top hat and distributive loading. Several interesting points were brought out by these experimental results. Fig. 25 shows that top-hat loading yielded the largest value of radiation resistance for a particular height. Surprisingly, the helical antenna[11] yielded a value less than midpoint loading. The three-quarter point and midpoint loading curves were not extended to lower values of height because data were very difficult to obtain below the points shown on the respective curves. The combinations of inductances and lengths below the heights shown on these two curves were probably beyond resonant conditions at the frequency used in the measurements. The other curves were extended by dashed lines indicating no difficulties were encountered in the measurements and other lengths were very possible.

Another interesting aspect of the top-hat loading curve is that a four-spoked wheel approaches to a good degree a solid disk. Doubling to eight spokes only improves the loading by about nine percent as noted in Table 7. Thus, *a few radials on the top of a vertical are very effective.*

Four radials at the base, approximating a ground system, are practically *useless* as noted in Fig. 24. Also, it can be seen from Table 7 that the reduction in length because of top-hat loading is approximately equal to twice the diameter of the disk.

On 160 meters, top hats have been made with sloping wires or struts with success.[12] Because of the sloping nature of this top hat, some cancellation of the antenna current takes place, thus reducing the radiation resistance further.

Although the curves in Fig. 25 were obtained from experiments at 7.21 MHz, these data can be applied to the other bands by proper scaling. For example, by doubling all dimensions, including the number of turns of the loading coils, the radiation resistance values would apply at a frequency of 3.6 MHz. By increasing the dimensions by only 1.85 instead of 2, the results would then apply to a frequency of 3.9 MHz. In like manner, a proper scaling factor could be used to apply these results to a portion of any of the amateur bands.

40- and 80-Meter Short-Vertical Designs

As was stated before, a most important consideration in designing short verticals is a knowledge of the input resistance and how it varies with different types of loading. The objective is to obtain a resistance value large compared to earth losses, so that efficient operation is obtained. In the author's specific case, using 115 radials, practically no earth loss was measured, and, hence, any radiation resistance above a few ohms assured good operation and an opportunity to verify the theoretical predictions for very short vertical antennas.

Since a broad-band, bifilar, 4:1 step-up transformer was available from previous work,[13] the first design was for the shortest vertical having an input resistance of 12.5 ohms. From the curves of Fig. 25, it appeared that a 16- or 17-foot (4.88- or 5.18-m) antenna with a coil of some 13 turns (extrapolated from Table 6) at 8 or 9 feet (2.44 or 2.74 m) from the base would provide the proper impedance at 40 meters. Further, it was decided that some 7 or 8 feet (2.13 or 2.44 m) of length above the coil could be replaced by an eight-spoked top hat having a diameter of 4 feet (1.22 m). The actual design that resulted, after proper tuning, is shown in the picture. The antenna had a total height of only 10 feet (3.05 m) and a 14-turn coil placed 1 foot (0.31m) below the top hat. This height was about one foot (0.31 m) higher than first expected, but upon careful examination it was noted that the top hat also reduced the radiation resistance, while replacing a section of the vertical portion. Therefore, the height had to be increased somewhat when considering top-loading effects. Also shown in a picture are the construction details for the top hat.

Two other shortened verticals for 40 meters were investigated. One was an 8-1/2-foot (2.59-m) helical using a 4-foot (1.22-m) top hat and 75 turns on a 1-5/8-inch (41-mm), 7-foot (2.13-m) long, wooden dowel. The input impedance was 7.5 ohms and it was matched with a standard pi network. Pictures are shown with the network. Several tests were made by doubling the winding pitch below and above the midpoint, keeping the number of turns constant, with very little difference in results.

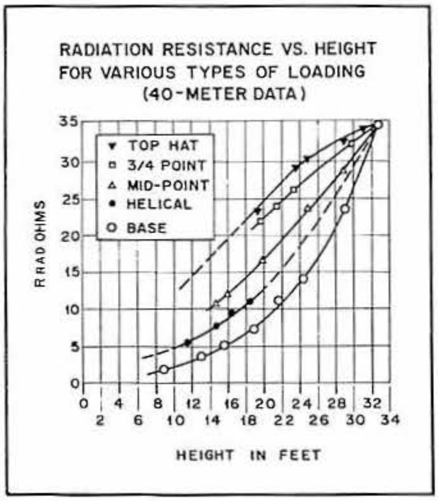


Fig. 25 — Experimental results of radiation resistance as a function of height of antenna for various types of loading (40-meter data).

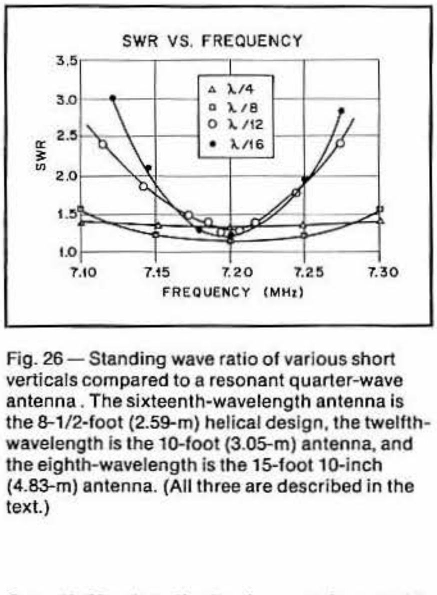


Fig. 26 — Standing wave ratio of various short verticals compared to a resonant quarter-wave antenna. The sixteenth-wavelength antenna is the 8-1/2-foot (2.59-m) helical design, the twelfth-wavelength is the 10-foot (3.05-m) antenna, and the eighth-wavelength is the 15-foot 10-inch (4.83-m) antenna. (All three are described in the text.)

The second antenna, also for 40 meters, using a 7-foot (2.13-m) top-hat, resulted in a matched vertical only 6 feet (1.83 m) high. It had a 14-turn coil, 6 inches (152 mm) below the top hat and an input impedance of only 3.5 ohms. Matching was accomplished with the 4:1 transformer and the pi network. A picture of the antenna and matching network is shown.

A larger 40-meter vertical antenna was also investigated. It had a 4-foot (1.22-m) top hat and 7 turns of base loading which resulted in a height of 15 feet 10 inches (4.83 m) (approximately 1/8 wavelength) and an input impedance of 12.5 ohms. The purpose of this design was to compare its low-angle radiation and bandwidth[14] with the other antennas. Table 8 shows the parameters of these various short vertical designs. Fig. 26 shows the SWR curves of three of the short antennas compared to a quarter-wave resonant vertical and Fig. 27 shows the SWR of the 6-foot (1.83 m) antenna.

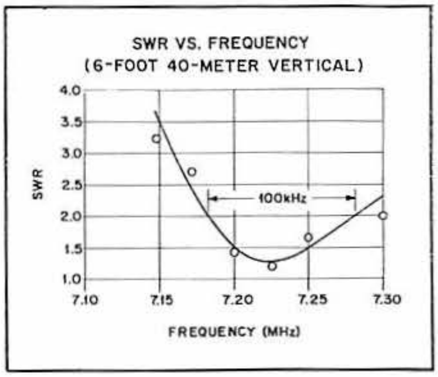


Fig. 27 — Standing wave ratio of the 6-foot (1.83-m) vertical using a 7-foot (2.13-m) top hat and 14 turns of loading 6 inches (152 mm) below the top hat.

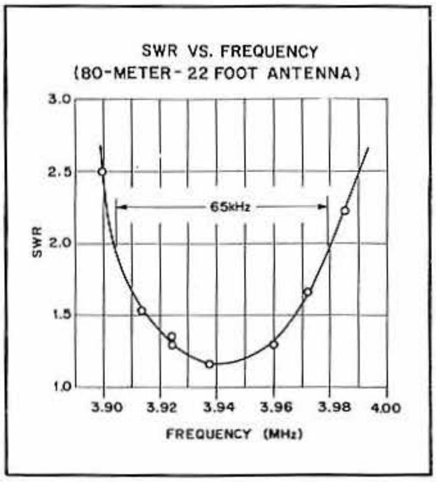


Fig. 28 — The standing wave ratio for the 22-foot (6.71-m), 80-meter vertical.

As can be seen by the SWR curves, shortening an antenna generally decreases its bandwidth. Also by comparing the 8-1/2- and 6-foot (2.59 and 1.83-m) antennas top-hat loading appears to affect the SWR the least. It should also be noted that an eighth-wavelength antenna appears to have a reasonable bandwidth and would probably result in a practical beam design.[15]

And finally, the four short-vertical designs described above were compared with a resonant quarter-wavelength antenna for low-angle radiation and on the air with other amateurs signals. The low-angle radiation measurements were made at three wavelengths in distance and at heights of 1, 3, 6 and 8 feet (0.31, 0.91, 1.83, 2.44 meters). This relates to vertical angles of 0.15, 0.45, 0.90 and 1.2 degrees, respectively. All measurements were made under matched conditions and with a constant 100 watts fed into the antennas under test. In no case were there any appreciable differences noted in the field strength measurements. In fact, the 6-foot (1.83-m) antenna seemed to give slightly higher readings! These measurements certainly tend to verify the theory on the power gain predicted for short verticals. On-the-air checks were again very gratifying and exciting. Over 200 contacts with the 6-foot (1.83-m) antenna strongly indicated the efficiency and capability of a short vertical. Invariably at distances greater than 500 or 600 miles, the short verticals yielded excellent signals.

As was stated previously, all of the results obtained by measurements on 40 meters can be scaled, by the appropriate ratios of frequencies, to other bands. This was tried out on 80 meters. Since a 7-foot (2.13-m) top hat was available (instead of an 8-foot [2.44-m] one), the height turned out to be 22 feet (6.71 m) instead of 20 (6.10 m). The loading coil had 24 turns and was placed 2 feet (0.61 m) below the top hat. On-the-air results duplicated those on 40 meters. The bandwidth was 65 kHz (half of the 40-meter value) as shown in Fig. 28.

Conclusions

Several interesting results came out of this investigation which, even to one schooled in antenna theory, are difficult to believe. The author refers specifically to the ability of very short verticals to radiate and receive as well as a full-size quarter-wave antenna. The differences are practically negligible. But, as was seen, the trade-offs are in lowered input impedances and bandwidths. However, with a good image plane and a proper design, these trade-offs can be entirely acceptable.

As a result of this investigation, other problems were noted which indicate the need for further experimentation. The writer refers specifically to the trade-offs encountered when shortening the radials (to 0.1 wavelength, for example), the efficiency of ground-mounted versus elevated verticals as a function of height above ground, the characteristics of a multiband vertical over a low-loss image plane, and a shortened vertical beam using elements of the order of an eighth wavelength.

Another point should be mentioned in relation to the results reported here. Even though they were obtained on short, ground-mounted verticals, they are valid for center-fed verticals or horizontal antennas as well. The only differences are that the impedance values should be doubled and the effect of the image antenna accounted for.

The author would like to acknowledge the support of many amateurs for their fine words of encouragement and excellent reporting during on-the-air contacts. In this study, some 350 amateurs reported on comparisons between signals from these short verticals and those of other stations. This material was originally presented in *QST* by Jerry Sevick, W2FMI.

References

[1] Sevick "The Ground-Image Vertical Antenna," *QST,* July 1971. Also appears elsewhere in this chapter.

[2] Sevick, "The W2FMI 20-Meter Vertical Beam," *QST,* June 1972.

[3] See footnote 1.

[4] Miller, Poggio, Burke, Seldon, "Analysis of Wire Antennas in the Presence of a Conducting Half-Space. Part II. The Vertical Antenna in Free Space," *Canadian Journal of Physics,* Vol. 50, 1972.

[5] Feldman, "The Optical Behavior of the Ground for Short Radio Waves," *Proc. of the Inst. of Radio Engineers,* Vol. 21, no. 6, June 1933.

[6] King, *The Theory of Linear Antennas,* Harvard Univ. Press, Cambridge, MA, 1956.

[7] See reference in footnote 6, p. 497.

[8] See reference in footnote 6, p. 190.

[9] See footnote 1.

[10] Weeks, *Antenna Engineering,* McGraw-Hill Book Company, 1968, p. 48.

[11] The diameter of the helical antenna was 1-5/8 inches (41 mm). Each helical antenna had a top hat 18 inches (457 mm) above the helix in order to terminate the upper turns with sufficient capacitive reactance.

[12] See reference in footnote 10, p. 44.

[13] See footnote 2.

[14] Bandwidth is defined as the range in frequency where SWR is less than 2:1.

[15] See footnote 2.

Optimizing Vertical Antenna Performance

Do you have tower restrictions, a small yard or patio, almost no room for antennas? If so, here are some suggestions for making your signal bigger in spite of the handicaps.

Antennas never cease to be a hot topic of conversation among amateurs; the interesting articles by John Stanley, K4ERO/HC1[1] and Roger Hostenback, W5EGS,[2] on the optimum grounding of vertical antennas have led the author to communicate these thoughts on the subject. Obstacles at the author's present location (typical of many suburban dwellings) place severe limitations upon where ground wires can be placed. These obstacles are large boulders, areas of concrete, the house, vegetable and flower beds, and the neighbors' property lines. It has not been possible to lay out radials of uniform length or of uniform angular distribution. Nevertheless, the author has had successful results with vertical antennas. Although the writer must make a number of statements which are based upon fragmentary evidence and are lacking in scientific rigor, they should be useful for suggesting how others might proceed to optimize their particular situations.

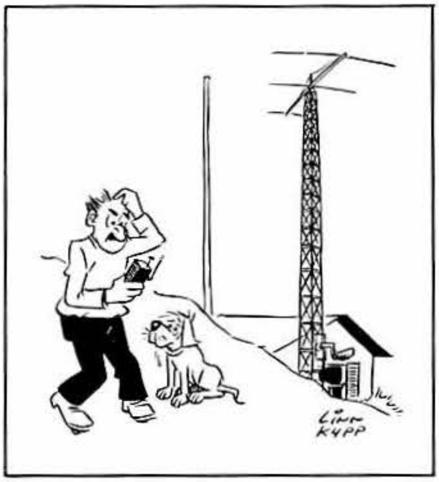
The writer has three very dissimilar vertical antennas. Much of the discussion will pertain to their individual ground systems, although strictly speaking they cannot be independent; a change of the grounding conductors of one vertical is bound to affect the others. For brevity the writer shall not discuss the methods of impedance matching of the antennas as this is a topic thoroughly covered elsewhere. The author *shall* mention some problems of using dissimilar antennas in a phased array, although the results are preliminary.

The three antennas are (1) a shunt-fed crank-up tower having a three-element triband Yagi on top, the height being variable from 27 to 41 feet (8.23 to 12.50 m); (2) a 40-foot (12.19-m) insulated base-loaded antenna consisting of a 30-foot (9.14-m) pipe mast topped by a whip, located approximately 70 feet (21.34 m) south of the tower and hereafter referred to as the "south antenna"; (3) about 20 feet (6.10 m) east of the tower, a vertical antenna termed the "north antenna," which was described in an earlier *QST* article.[3] Fig. 29 shows the layout. The north antenna has been used with various heights up to 40 feet (12.19 m) but in the present experiments it is used in its "summer" configuration with a height of 25 feet (7.62 m) and with a 7/14-MHz trap located 10 feet (3.05 m) from the base. For 3.5-MHz operation additional loading is supplied at the base.

The Grounding Systems

None of the three verticals have anything approaching an optimum ground system; while the south antenna has the best on paper, it is not necessarily the best in performance. When the south antenna was first placed into operation the grounding system consisted of about 200 feet (60.96 m)

How do you ground a vertical antenna when there is no ground?



Optimizing ground-wire currents is well worth the time and effort required.

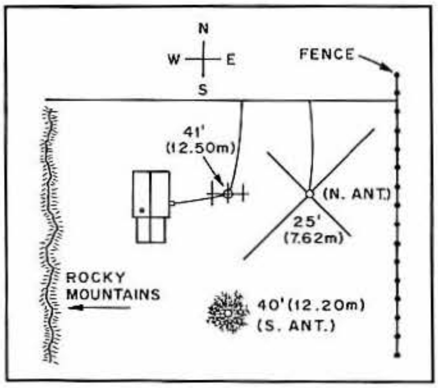


Fig. 29 — The W0JF backyard, with antenna farm.

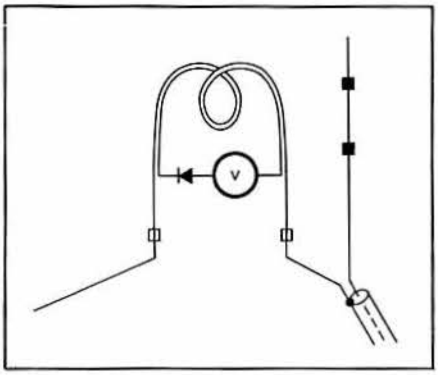


Fig. 30 — Suggested substitute for a thermocouple ammeter.

of wire distributed among a few conductors which went out more or less radially. One was about 60 feet (18.29 m) long, the others 30 feet (9.14 m) or less. On 7 MHz the performance was generally inferior to that of a horizontal half-wave dipole 30 feet (9.14 m) above ground. Later, the ground system was augmented to utilize about 1000 feet (304.80 m) of wire, and the vertical then began outperforming the dipole.

While the author foresaw Stanley's statement that possibly not all of this additional wire would be effective, it was assumed that any wires added at least would do no harm, and the writer tried to put wires in the entire immediate area of the antenna, subject to the constraints mentioned above. Several of the radials have bends to avoid obstacles. In a few cases a single wire goes out from the antenna to a junction some distance away, and then several wires fan outward from the junction. Three wires are connected at the far ends to a few square feet of chicken wire. Where the wires are in shrubbery they are above ground; otherwise they are an inch or two (25 or 51 mm) below. None of the additional wires were as long as 60 feet (18.29 m), and the lengths were generally determined by the obstacles they encountered. Haphazard as this system was, the improvement was spectacular.

While making this change in the south antenna's grounding, the author carried out two simple experiments. First, when operating at 7 MHz, a 33-foot (10.06-m) piece of wire was added, which in free space would be 1/4-λ long, but which when laid on the ground would be longer (in wavelengths). The writer connected it to the rest of the ground system through a thermocouple ammeter, and read the current while applying power. With this wire then cut in half and laid out as separate radials in opposite directions, it was found that the total current increased. Cutting these 1/8-λ pieces in half and distributing the resulting fragments as four radials in directions at 90 degrees to each other caused the total current to decrease. These observations led the author to conclude that for a given total amount of wire the most efficient layout would be radials having lengths of about 1/8 a free-space wavelength. This conclusion is consistent with Stanley's Table 1.[1]

In the other experiment, the author also used a 33-foot (10.06-m) piece of wire, but half of it was no. 34 and half no. 12 wire. With the thick end adjacent to the antenna, the current was higher than with the wire turned around so that the thin end was adjacent. The experiment showed that wire diameter is of some consequence, and it is more important to have heavy conductors close to the antenna.

The Tower and the North Antenna

Grounding of the tower is very heterogeneous; first of all, of course, the bottom of the tower is buried in the ground some 8 feet (2.44 m). There are two radials about 25 feet (7.62 m) long going in a more or less southerly direction, then a short wire going to a water faucet on the wall of the house. Finally, and probably most important, there is a wire that goes northward about 20 feet (6.10 m) and makes a junction with the middle of a 120-foot (36.58-m) east/west wire. The eastern end of this wire is located at the common corner with the property of the neighbor to the northeast and at that point is bonded to his extensive chain link fence. About 25 feet (7.62 m) west of this bond to the fence, there is a junction with a southward wire which is connected to the base of the north antenna. Otherwise, the grounding system of the north antenna, consisting of a few radial wires, is as described in the earlier *QST* article.

Some observations were made by connecting a thermocouple ammeter and a selection of capacitors and inductors in series with various conductors connected to the base of the tower. On 3.5 MHz, with the wire that goes to the fence, the author found a very strong resonance using a 300-pF capacitor. No such resonance was found with this wire of 7 MHz nor on 1.8 MHz, nor did there seem to be any resonance with any of the other wires.

No attempt has been made to bond the upper and lower sections of the tower (where they telescope) together. No such bonding seems necessary, except in the rare case of an extremely strong wind, when there is some receiver noise resulting from poor conductivity between the sections. Cranking the tower up and down seems to have little effect upon the degree of impedance mismatch.

On 3.5 MHz, using a power of about 150 watts, the author had contacts all over the world using this shunt-fed tower, usually not cranked all the way up. The south antenna has also given fairly good account of itself, but with its thousand feet (304 m) of radial wires its performance is still not quite as good as that of the tower with its meager "black magic" grounding.

On 7 MHz, the behavior of the tower is the reverse even though the impedance match is somewhat superior to that on 3.5 MHz. The performance, despite the good match, is far inferior to the south antenna or even the north antenna. Offhand, one would expect the performance, such as it is, to be better with the tower cranked down to minimum height, when it would be close to 1/4λ, but the few reports received on the air indicate better performance is obtained at maximum height. The overall performance of the tower on 7 MHz is a complete mystery.

The author has used the tower on 1.8 MHz only rarely, but has worked as far as 1000 miles, even though there is a very bad impedance mismatch on the feed line. One of the author's future projects is to cure that, since the tower may be magic on the top band, too!

What if You Don't Have a Thermocouple Ammeter?

The preceding discussion has, the author hopes, suggested that individuals may be able to optimize their ground systems by measuring the currents in individual ground wires. In this regard the writer has been fortunate in having available a number of thermocouple ammeters, instruments not commonly available in ham shacks. However, it was found easy to make a substitute which can serve to measure relative current and to detect resonances. Take a short length of twin-lead, speaker cord or similar cable, about a foot (0.305 m) long. Connect one wire of the pair in series with the circuit to be studied (the ground wire). Connect the two ends of the other wire of the pair to a semiconductor diode and a sensitive dc meter in series (Fig. 30). For convenience and for reproducibility in results, coil the cable up and secure it to a terminal board.

Using Dissimilar Antennas in a Phased Array

The author can use any two of the three verticals as a phased array by connecting the feed lines in parallel at the transmitter. In the shack the author has a switchboard that can switch additional lengths of line in series with one antenna or the other. The writer does not attempt to change the impedance match at the bases of the individual antennas, but does generally retune the transmitter as the phasing is changed. Some of the effects observed must be attributed to variations in impedance mismatches rather than to basic changes in directivity. Nevertheless, some gain can usually be obtained by combining the verticals in one way or another.

In the use of two dissimilar antennas, two questions arise which may not apply when identical antennas are used. First, is there really an advantage in using the two of them in a phased array over using the better of the two alone? The relevance of this question may be seen by considering the extreme case where one is very much better than the other. In such a case the field strength of the poorer one is so much less that there is little difference whether it is in or out of phase with the field of the better one, and there can be little or no observable directional effect when the two are used together. Furthermore, the power supplied to the better antenna is cut in half while the other half of the power is largely wasted.

This simple argument suggests that in most cases the two antennas should be nearly equal in the field strengths they produce if they are to be effective in a phased array. However, the actual situation is sufficiently complex that exceptions may be found. For one thing, the better antenna may have "blind" directions in its pattern because of obstructions, and the poorer one may help to fill those in. Also, the impedance effects which have been mentioned before are hard to predict. The author can only suggest that one may find it worthwhile to try using two such antennas together, and may find unexpected advantages in some directions.

On 3.5 MHz the north antenna is generally much poorer than the tower. However, in some directions observers have consistently reported a small gain in using the two together over the tower alone. Incidentally, it should be mentioned that observations made on receiving are not reliable tests, partly because of impedance effects. Also, some of the noise received may be generated locally and its effect may mask the true pattern of the array. The only reliable evaluation is by transmitting to distant observers.

The second question concerning dissimilar antennas involves solving for an unknown quantity: the relative phase of the two antennas. The relative phase of the field of an antenna is *not* determined solely by the length of the transmission line connecting it to a transmitter. The impedance of the antenna usually contains a reactive component, and its presence gives rise to a phase shift. With two identical antennas these phase shifts are the same and do not affect the relative phase between the two antennas, which is determined only by the difference in feed-line lengths. With dissimilar antennas these phase shifts are generally not identical, and they may vary in different ways with shifts in frequency or with variations in the moisture content of the earth. Not unrelated was a discovery made when changing the grounding of the south antenna from 200 feet (60.96 m) of wire to 1000 (304.80 m). There was a substantial change in the phasing when it was used in an array with the tower.

The author has experimentally answered this phasing question by setting up a small probe antenna at a point equally distant from the two antennas and connecting it to a field-strength meter. The line lengths are varied until a minimum (usually quite sharp) is observed. Then it is known that the antennas are 180 degrees out of phase, and the array is a bidirectional end-fire one (W8JK). If the author adds or subtracts 1/2 λ of line from one antenna, the antennas should be in phase and a maximum should be observed. The experimental observations are in agreement with such predictions. If a length of line equal in electrical wavelengths to the spacing between the antennas is then added or subtracted from the feed line of one of them, the combination approximates a unidirectional end-fire array. The favored direction is away from the element which has the longer equivalent feed line (larger phase shift from the transmitter).

To reiterate, the results with phasing dissimilar verticals are very preliminary, and there is little that can be said about them except for the fact that at times very noticeable gains over using the better single antenna are observed.

Vertical Versus Horizontal Antennas

The author used some *horizontal* antennas and observed the differences in performance between them and the vertical antennas at a particular location. Horizontal antennas were not tried on 7 and 3.5 MHz any higher than 30 feet (9.14 m) above ground, however.

The first foothills of the Rocky Mountains rise up immediately to the west of the author's QTH, the nearest ones subtending a vertical angle of about 10 or 15 degrees. As expected, propagation to the west is usually difficult. To the east there are some power wires running north and south. The land slopes off to the north, and has a line-of-sight view for 12 miles from the base of the antenna tower.

The writer finds a tendency for horizontal antennas to be superior to the west, over the mountains, and for verticals to be superior to the east. Standard theory explains these findings as follows: Probably many of the signals coming over the mountains are scattered by the surface of the ground. Those familiar with advanced electromagnetic theory remember that according to the Fresnel equations, the reflection coefficient is greater when the wave is polarized with the electric vector parallel to the surface (i.e., horizontal). Therefore, this scattered radiation is probably horizontally polarized. On the other hand, the electric field from the vertical antenna is perpendicular to the direction of the power wires and is less disturbed by them than the field of a horizontal antenna.

Although very few firm results were presented, the author hopes he has suggested some procedures which will help those facing restrictions on grounding systems they can use. With a little persistence and ingenuity, they should be able to build effective antennas. It *is* possible to evaluate simple arrays yourself and to improve their performance according to your own communication requirements. This material was originally presented in *QST* by Yardley Beers, W0JF.

References

[1] Stanley, "Optimum Ground Systems for Vertical Antennas," *QST*, December 1976.

[2] Hoestenback, "Improving Earth-Ground Characteristics," *QST*, December 1976.

[3] Beers, "Short Antennas for the Lower Frequencies," *QST*, September 1970.

Some Plain Facts about Multiband Vertical Antennas

Does engineering jargon, page-long equations and references to the *IEEE Proceedings* have you gnawing your nails in frustration? Take heart, for these bits of knowledge about multiband vertical antennas are given in plain lingo.

During discussions with newcomers, and old-timers for that matter, it becomes apparent that there is considerable confusion as to what exactly a multiband vertical antenna is. The confusion concerns the method of feed, how much mismatch one can expect, how many radials are required, how the particular antenna is built for multiband use, plus some other points.

This article breaks the subject into simple language and provides the reader with sufficient expertise to assure him that he won't wind up with a system he really doesn't want. Before going into a discussion of the different types of multiband "verticals" we will offer some simple antenna facts.

Some Basic Theory

The term "multiband antenna" has come to mean many things to hams. With trap antennas, tapped coils, random wires, and so forth, there is plenty of reason for the confusion. Simply, a multiband antenna is one that can be used on more than one band. How we make it work on different bands is another story.

Basically, any piece of wire of *any* length can be classed as a multiband antenna. For example, a length of wire 4 feet (1.22 m) long *could* by used on *any* amateur band, from 160 meters on up. But how well the piece of wire would work is a completely different matter.

In the feed point of any antenna there is *radiation resistance.* The energy supplied to an antenna is dissipated in the form of radio waves and in heat losses in the wire and nearby insulating materials. The radiated energy is the useful part, but so far as the transmitter is concerned it represents a power consumption just as much as does the energy lost in heating the wire. In either case the dissipated power is equal to I^2R; in the case of heat losses, R is a real resistance (ohmic losses), but in the case of radiation, R is an *assumed* resistance. This fictitious resistance is the radiation resistance. This brings us to our first important point about multiband antennas.

Whenever one reduces the size (length) of an antenna physically, the radiation resistance is reduced also. As an example, assume we have a 20-meter quarter-wave antenna, which is approximately 16 feet (4.88 m) long. Let's imagine we made it out of no. 40 wire, which has a resistance of about 1 ohm per foot, (0.31 m). The radiation resistance of a resonant quarter-wave vertical operated against a perfect ground is on the order of 35 ohms. In this case, the feed-point impedance of our antenna would be roughly 35 ohms in radiation resistance plus 16 ohms in ohmic resistance. If we were to feed 51 watts into this antenna 16 watts would be dissipated as heat (lost power) and the remainder — 35 watts — would be radiated. Now, suppose we use this same antenna on 80 meters. As mentioned above, when we reduce the size of an antenna physically the radiation resistance is also reduced. On 80 meters our 16-foot (4.88-m) antenna would have a radiation resistance on the order of 1 ohm! However, we would still have the ohmic resistance of 16 ohms. It doesn't take much figuring to realize that just about all of our power would be lost as heat.

Of course we wouldn't use no. 40 wire for such an antenna. More likely the antenna would be made from aluminum tubing and the ohmic losses would be very low, but probably still more than the radiation resistance. There is an old axiom in Amateur Radio that offers some pretty good advice: Always make the antenna as long as possible and erect it as high as possible. Also, there is a joke that goes with that axiom — if such an antenna stays up, it is too small!

At this point we have only mentioned radiation and ohmic resistance in the antenna feed point. These are the two resistances that exist when the antenna is resonant. When the antenna is not resonant, there is reactance present in the feed point. Reactance is also expressed in ohms, but it isn't a real resistance in the sense that power can be dissipated therein. We won't go into a long discussion on reactance because it would take up too much space. An excellent explanation can be found in the League publication, *Understanding Amateur Radio.* Simply, reactance can be likened to a gate or door that stops or hinders the flow of current into a circuit. When an antenna is operated at some frequency other than the resonant frequency there will always be reactance present. Keep in mind that with *any* antenna, multiband or otherwise, we always have a condition on some band or frequency where the antenna is not resonant. Therefore, there will be reactance at the feedpoint.

Types of Vertical Antennas

The basic and most popular type of vertical is one that is a quarter wavelength long and is operated against ground or in a groundplane configuration. The antenna is usually made from tubing and the radials are wire. An ideal groundplane (simulated earth ground) would be a sheet of metal with

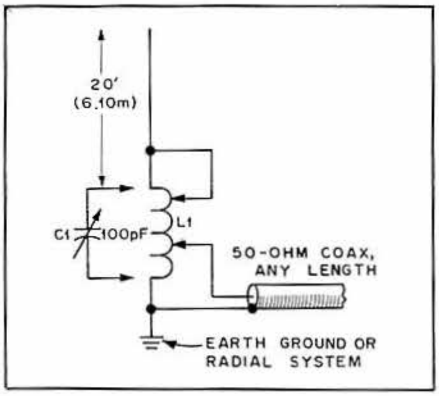


Fig. 31 — A typical multiband vertical antenna. A description of the system is given in the text.

a radius of one-quarter wavelength or more. However, this is only practical at vhf so the customary method is to use wires as the radials. Probably the number one question asked about groundplane antennas is, "how many radials are required?" The answer is simply, the more radials used, the better the antenna will perform, at least up to a certain point. This should not be construed to mean that an antenna with only two or three radials won't work. Such an antenna will work, but for *maximum* performance one should consider 40 or more radials. If the reader is interested in performance data for a few radials versus many, he should read the article in *QST* by Sevick.[1]

The feed-point impedance of quarter-wave groundplane is on the order of 35 ohms. The impedance can be raised by drooping the radials down until a 50-ohm match is obtained. Exactly how much droop is required depends on the number of radials.

The quarter-wave groundplane is essentially a single-band antenna. However, a 40-meter quarter-wave vertical can also be used on 15 meters, a happy circumstance for the Novice. In this case, a 40-meter quarter wave works out to be three quarter waves on 15 and any *odd* multiple of quarter waves will provide a relatively low-impedance feed.

Multiband Verticals

When we get into the field of multiband verticals we find that considerable confusion exists. As pointed out previously, *any* antenna can be *called* a multiband antenna, but how we get power into such an antenna is another matter.

Up until the '50s any amateur multiband antenna was a system that usually consisted of an antenna, tuned feeders, and an antenna coupler. In the early '50s more and more amateurs started to use coaxial cable for feeders, along with band-switching transmitters. The next logical step was the use of a multiband antenna system that required no adjustments and always presented a matched condition to the feed line — in other words, an antenna that had a 50-ohm feed-point impedance on every desired band and frequency within a given band. A logical development was the multiband trap antenna.

By inserting traps in an antenna it was possible to make an antenna "look" like a resonant half-wave dipole in whichever band was used; or, in the case of multiband verticals, making the vertical look like a resonant quarter-wave antenna for the desired band. However, and this is important as far as the newcomer is concerned, to our knowledge there is *no* multiband trap antenna that will provide a perfect match on all bands, *regardless* of what some antenna manufacturers may tell you. Many hams have spent countless hours trying to adjust trap antennas for that "perfect" match when actually, it is just about impossible to obtain such a condition.

Nontrap Multiband Verticals

Several antenna manufacturers sell multiband antennas that consist of a vertical piece of tubing, usually 16 to 20 feet (4.88 to 6.10 m) long. The tubing is used with a loading coil at the ground end. By making appropriate taps and adjustments on the coil the antenna can be matched (or closely matched) on any given band. This type antenna has *no* traps. This in turn means that the coil taps and adjustments *must* be altered when one changes bands. Some misguided amateurs buy these antennas expecting all they need do is put them up and the antenna will work on all bands, automatically. Let's make one point clear: such an antenna *is* a multiband antenna, but requires adjustment *at the antenna* when one changes bands.

Of course, the next question should be, "If the antenna is that simple can't I build my own?" Yes, it is a very simple multiband antenna to make and install. Two or three sections of inexpensive 10-foot (3.05-m) TV mast sections can serve as the vertical radiating element. The mast can be supported on an insulator, such as a beverage bottle, and the mast guyed with nylon line. Fig. 31 shows a diagram of the antenna system. L1 should be a coil made of bare wire, no. 12 or 14, so that it can be tapped at every turn. A convenient coil size is 2-1/2 inches (64 mm) in diameter, six turns per inch (25 mm), such as B & W 3905-1 stock. The number of turns required, assuming 80 meters as the lowest band to be used, should be about 30 turns with an antenna length of 25 feet (7.62 m).

Adjustment of the antenna requires the use of an SWR bridge. Connect the coax line across a few turns of L1 and make a trial position of the shorting tap. Measure the SWR, then try various positions of the shorting tap until the SWR reaches its lowest value. Then vary the line tap similarly. This should bring the SWR down to a low value. Small adjustments of both taps should provide an SWR close to 1. If not, try adding C1 and repeat the adjustment procedure, varying C1 each time until a match is achieved. Radials will enhance the performance of the antenna. The number of radials is up to the individual amateur.

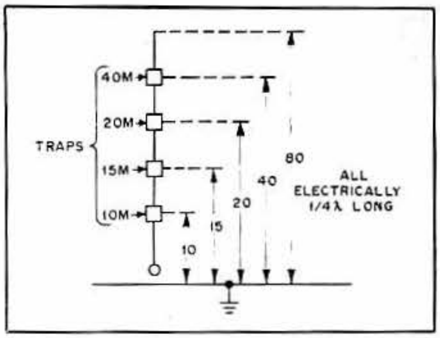


Fig. 32 — Drawing of the theoretical multiband trap vertical. In commercial practice, certain traps may be grouped together, giving the impression that only a single trap is used.

Trap Verticals

As mentioned earlier, traps can be installed in a multiband vertical. These traps are usually parallel-tuned circuits and the objective is to make each section of the antenna work as a quarter-wave vertical or odd multiple thereof on the desired band. Fig. 32 shows an example of this type antenna.

The purpose in using this type antenna is to provide a system that always presents a matched condition for the feed line. Unfortunately, there is so much interaction between various sections of the antenna that it is impossible to come up with a *perfect* match on each band. What is an *acceptable* match is another story.

Amateurs as a whole are inclined to attach too much importance to an SWR of 1. They feel that if their SWR bridge isn't showing an absolute zero reflected power that something is horribly wrong and they won't work out. The plain fact is that using a feed line such as RG-8/U (assume a 100-foot [30.48 m] length) one could have an SWR of as much as 5:1 and have *no* appreciable loss in the system. However, there is one clinker in this thinking!

In many instances commercially made transmitters and transceivers are designed by the manufacturer to work into a 50-ohm load only. They don't allow much leeway from this figure. When there is a mismatch in the antenna system, it can become impossible to load and tune the final amplifier of the transmitter. There just isn't enough tuning range in the tank circuit of the amplifier to handle the reactance that may be present in the load. There is a way around this problem however, and that is using a Transmatch in the feed line to disguise the mismatch.[2] The Transmatch can be adjusted so that the transmitter "sees" a 50-ohm load regardless of the mismatch at the antenna.

The Harmonic Problems

Another consideration should be mentioned. As pointed out earlier, *any* antenna can be a multiband antenna. By the same token any harmonics generated in the transmitter that reach the antenna can be radiated. It is true that a single-band antenna will reject harmonic energy, but *not* completely. In the case of a multiband trap antenna there is no rejection of some harmonics, simply because the antenna is designed to be resonant on all hf amateur bands. The solution to this problem is the use of a selective circuit installed in the feed line. A Transmatch is such a circuit and should provide adequate harmonic rejection.

Some Other Thoughts

The question is frequently asked, "Should I mount my vertical on the ground, or get the base up in the air?" Getting the antenna up in the clear is always better than having it mounted at earth level and surrounded by rain gutters, house wiring, trees, power lines and so forth. However, getting the vertical antenna up in the air also means that radials, as many as possible, should be used. The average installation (if there is such a thing) usually consists of three or four radials (or more) cut for the lowest operating frequency. Such a system should give a good performance.

Another important matter is that of the earth ground. When verticals are mounted at ground level the ground losses can be very important. Too many amateurs buy their verticals, get a 5-foot (1.52-m) long TV-type ground rod and drive it into the earth at the base of the antenna. They think this provides a good ground connection. As a matter of fact, the TV-type ground rods are practically worthless for amateur work. A *good* ground rod is the type used by the power company for home installations. This is a rod that is heavily galvanized, 5/8 inch (16 mm) in diameter, and about 10 feet (3.05 m) long. The amateur should be able to buy these rods from any wholesale electrical supply house. If possible, tie your ground connection to the water-system piping, assuming metal piping is used.

You'll hear the statement from fellow hams that verticals are poor antennas and radiate poorly in all directions. This isn't true, because a vertical *can* by a good antenna, but you have to give it a fighting chance. This material was originally presented in *QST* by Lewis McCoy, W1ICP.

References

[1]Sevick, "The Ground-Image Vertical Antenna" *QST*, July 1971. Also appears elsewhere in this chapter.

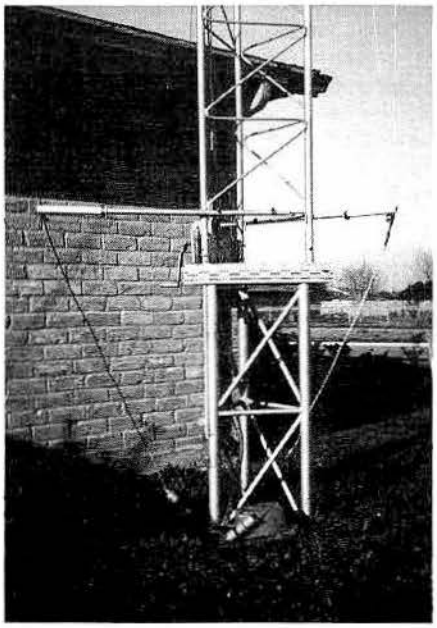
[2]A suitable Transmatch is described in the transmission-line chapter of any edition of *The Radio Amateur's Handbook*.

Shunt-Feeding Towers for Operation on the Lower Amateur Frequencies

The 160- and 80-meter DX antenna you've dreamed about may already be standing on your property — just waiting to be used as a DX vertical. Read this presentation and learn how to shunt-feed your tower on 1.8 and 3.5 MHz!

Shunt-feeding a tower used to support beam antennas for 14 MHz or higher frequencies has obvious advantages for the amateur who wants to work all lower bands. If a good ground system is installed, the result may be a very effective antenna for DX work on 80 and 160. The shorter tower installations may work very well on 40 meters, if the effective height above ground is less that 5/8 wavelength. Beyond this height the radiation angle goes higher, and the effectiveness for DX goes down.

The shunt-fed tower is at its best on 160, where a full quarter-wavelength vertical antenna is rarely possible. Almost any tower height can be used. If the beam structure provides some top loading, so much the better — but anything can be made to radiate, if it is fed properly. A self-supporting, aluminum, crank-up, tilt-over tower is used at W5RTQ with a TH6DXX tribander mounted at 70 feet (21.34 m). Measurements showed that the entire structure has about the same properties as a 125-foot (38.10-m) vertical. It thus works quite well on 160 and 80 in DX work requiring low-angle radiation. It can also be used on 40, but results are rather poor because of high radiation angle. WB5FKX, with a 37-foot (11.28-m) tower and a 21-MHz beam, finds that shunt feed on 40 enables him to work DX that he never knew existed before.



Close-up view of the base of the shunt-fed tower, showing the two bottom arms and their insulators.

Preparing the Structure

Usually some work on the tower system must be done before shunt-feeding is tried. Metallic guys should be broken up with insulators. They can be made to simulate top loading, if needed, by judicious placement of the first insulators. Don't overdo it; there is no need to "tune the radiator to resonance" in this way. If the tower is fastened to a house at a point more than about one-fourth of the height of the tower, it may be desirable to insulate the tower from the building. Plexiglas sheet, 1/4-inch (6-mm) or more thick, can be bent to any desired shape for this purpose, if it is heated in an oven and bent while hot.

All cables should be taped tightly to the tower, preferably on the inside, and run down to the ground level. It is not necessary to bond shielded cables to the tower

Table 9

Shunt-Feed Details for Several Towers Used on 160 Meters

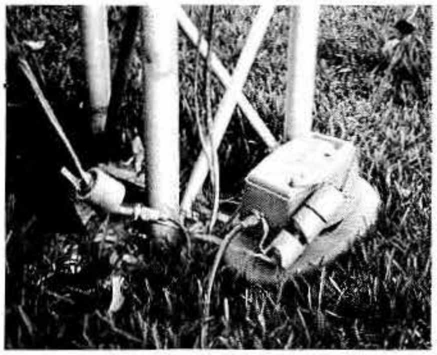
Station	Height of Tower (ft)	"Top-Hat" (Beams)	Average Height of Beam (ft)	Height of Wire-to-Tower Connection (ft)	Wire-to-Tower Spacing (in.)	Tuned Value of Gamma Capacitor
W5RTQ	69	TH6DXX	70	68	30	150 pF
K5PFL	86	Stacked 40, 20, 15, 10 M beams	95	75	24	125 pF
K4PUZ	64	TH6DXX	66	63	8	300 pF
K8KAS	70	TH6DXX	77	68	24	225 pF
W1CER	50	QST 20-M DX Weasel	55	47	44	400 pF

1 ft = 0.3048 m
1 in. = 25.4 mm

electrically, but there should be no exceptions to the down-to-the-ground rule.

No rf problems have developed with rotators, beam traps, or even TV sets where the TV antenna is part of the radiating structure, as is the case at WB5FKX. His only precaution was use of coax on the TV antenna. It would be well to proceed with caution, as every installation could be different in this respect.

Though the effects of ground losses are less severe with the shunt-fed vertical than with the simple quarter-wave antenna, a good system of buried radials is very desirable. The ideal would be 120 radials, each 250 feet (76.20 m) long, but fewer and/or shorter ones must often suffice. You can sneak them around corners of houses, along fences or sidewalks, wherever they can be put a few inches under the surface, or even on the earth surface. Aluminum clothesline wire is used extensively at W5RTQ, and it stands up well. Neoprene-covered aluminum wire may be safer in highly acid soils. Contact with the soil is not important. Deep-driven ground rods, and connection to underground copper water pipes, are good, if usable.


Though variable capacitors are shown in Fig. 33, they were all replaced with fixed-value units except one, which is inside a plastic box at the tower base.

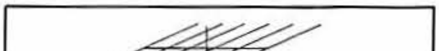

CONNECTION TO TOWER
NO. 8 COPPER SPACED 30" (0.76m) MAX. FROM TOWER
80/75-METER FEED WIRE, NO. 8 ALUMINUM SPACED 15"(0.38m) FROM TOWER
STANDOFF INSULATOR
STANDOFF INSULATOR
150-pF VARIABLES
250-pF VARIABLE
BURIED RADIALS CONNECTED TO BASE OF TOWER
COAXIAL FEED

Fig. 33 — Principal details of the shunt-fed tower at W5RTQ. The 160-meter feed, left side, connects to the top of the tower through a horizontal arm of 1-inch (25-mm) diameter aluminum tubing. The other arms have stand-off insulators at their outer ends, made of 1-foot (0.31-m) lengths of plastic water pipe. The connection for 80/75, right, is made similarly, at 28 feet (8.53 m), but two variable capacitors are used, to permit adjustment of matching with large changes in frequency.

Installing the Shunt Feed

Principal details of the shunt-fed tower for 80 and 160 meters are shown in Fig. 33. Rigid rod or tubing can be used for the feed portion, but heavy gauge aluminum or copper wire is easier to work with. Flexible stranded no. 8 copper wire is used for the 160-meter feed at W5RTQ, because when the tower is cranked down, the feed wire must come down with it. Connection is made at the top, 68 feet (20.73 m), through a 4-foot (1.22-m) length of aluminum tubing clamped to the top of the tower, horizontally. The wire is clamped to the tubing at the outer end, and runs down vertically through standoff insulators. These are made by fitting 12-inch (0.31-m) lengths of PVC plastic water pipe over 3-foot (0.91-m) lengths of aluminum tubing. These are clamped to the tower at 15 to 20-foot (4.57 to 6.10-m) intervals, with the bottom one about 3 feet (0.91 m) above ground. The lengths given allow for adjustment of the tower-to-wire spacing over a range of about 12 to 36 inches (0.31 to 91 m), for impedance matching.

The gamma-match capacitor for 160 is a 250-pF variable with about 1/16-inch (1.6-mm) plate spacing, which is adequate for the power levels presently authorized. The omega match used for 80 and 75 permits retuning for large excursions in frequency encountered in using both cw and phone on this band. Two capacitors are required, each about 150 pF, with plate spacing of about 3/16 inch (4.8 mm), if full power is used. They can be mounted in plastic refrigerator containers for protection against the weather. Use well-insulated knobs to avoid rf burns during the adjustment process.

Separate 50-ohm lines run underground to the station. The shield side of their connectors should be grounded to the base of the tower and to the buried radials as directly as possible.

Tuning Procedure

It is suggested that the 160-meter wire be connected to the top of a structure 75 feet (22.86 m) tall or less. Note, from Table 9, that the monster at K5PFL was fed at 75 feet (22.86 m) above ground. Mount the standoff insulators so as to have a spacing of about 24 inches (0.61 m) between wire and tower. Pull the wire taut and clamp it in place at the bottom insulator. Leave a little slack below to permit adjustment of the wire spacing, if necessary.

Adjust the series capacitor in the 160-meter line for minimum reflected power, as indicated on an SWR meter connected between the coax and the connector on the capacitor housing. Make this adjustment at a frequency near the middle of your expected operating range. If a high SWR is indicated, try moving the wire closer to the tower. Just the lower part of the wire need be moved for an indication as to whether reduced spacing is needed. If the SWR drops, move all insulators closer to the tower, and try again. If the SWR goes up, increase the spacing. There will be a practical range of about 12 to 36 inches (0.31 to .91 m). If going down to 12 inches (0.31 m) does not give a low SWR, try connecting the top a bit farther down the tower. If wide spacing does not make it, the omega match shown for 80-meter work should be tried. No adjustment of spacing is needed with the latter arrangement which may be necessary with short towers or installations having little or no top loading.

The two-capacitor arrangement is also useful for working in more than one 25-kHz segment of the 160-meter band. Tune up on the highest frequency, say 1990 kHz, using the single capacitor, making the settings of wire spacing and connection point permanent for this frequency. To move to the lower frequency, say 1810 kHz, connect the second capacitor into the circuit and adjust it for the new frequency. Switching the second capacitor in and out then allows changing from one segment to the other, with no more than a slight retuning of the first capacitor.

The omega match is recommended for 80-meter operation, because of the wide tuning range required. It was found that the point of connection could be at 28 feet (8.53 m), using a single support at the top of the first tower section. This served as a mount for the second standoff insulator for the 160-meter feed, as well.

A 40-meter feed, not shown, was connected at about 20 feet (6.10 m) up, with about 8 inches (203 mm) spacing between wire and tower.

Substituting Fixed-Value Capacitors

Depending on the frequencies used and the matching problems in a given installation, it may be possible to put fixed-value capacitors in place of some or all of the variables shown in Fig. 33, and then switch them remotely, or by hand, when changing frequency. This was done at W5RTQ. The 160-meter gamma capacitor is now a fixed-value, 150-pF type designed for high rf current service. It does not have to be weatherproofed, and it gives a satisfactory match over the small frequency range used on this band.

Two or three similar capacitors connected in series are used in covering the cw and phone frequencies in the 80-meter band. Operation around 3800 kHz requires about 50 pF in the omega (parallel) capacitor, so the three 150-pF units are used in series. Moving to cw operation near 3500 kHz requires about 75 pF, so only two 150-pF capacitors are used in series. The only variable now in the system is the 150-pF capacitor mounted in the plastic refrigerator box at the base of the tower. It is the series or gamma capacitor in the 80-meter feed. Even this could be replaced with a fixed unit, as it has been found unnecessary to adjust it in the course of normal operation of the station, if only small changes in frequency are made in using the two modes.

Because every tower installation is likely to be different from every other one in some respects, the values and dimensions given here may be subject to change, but the general principles should hold. Proof of this was found in the May 1975 issue of *Ham Radio,*[1] wherein W4OQ describes shunt-feeding in very similar terms. He also presented estimates of the electrical height of various tower-beam combinations that prospective shunt-feed users should find of interest.

It is hoped that this information will inspire others to try shunt-feeding their towers. This method offers an effective way to fire up on the lower frequencies that is useful to many who may have wanted to work these amateur frequencies but have shied away from doing so because of limited antenna space. This material was originally presented in *QST* by Earl W. Cunningham, K6SE.

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[1] True, "Shunt-Fed Vertical Antennas," *Ham Radio,* May 1975.

The Minooka Special

This 160-meter vertical antenna could be just the one for you, if you reside on property of city-lot size or are a mobile operator. You can make it from readily available, inexpensive material.

Inspiration for the design offered here resulted in part from the author's survey of antennas in use by 160-meter operators, worldwide. An extensive report was compiled, which filled a loose-leaf notebook! A boil-down of the most useful information resulted in an 11-page report which was made available to numerous amateurs. Subsequently, the writer was encouraged to submit some of the data for publication. Approximately 60 operators were polled. The following information from that inquiry should be of interest to those who are curious about "preferred" antennas for top-band use.

Question 1: "If you could put up any antenna for 160, what would it be?" *Result:* 60% favored verticals, 30% said horizontals, and 10% indicated mixed feelings. (The term "vertical" includes various configurations — 1/4, 1/2, and 5/8 wavelength, vertical arrays, and inverted Ls.)

Question 2: "Comparing antennas that an average ham could build, do you prefer verticals or horizontals for 160?" *Result:* 70% said vertical, 17% favored horizontal, 5% inverted L, 2% horizontal and vertical, 2% inverted V, and 3% had no opinion. Reasons given for the responses were, "Because of signal comparisons and past experience. A backyard-compatible vertical is more effective than a backyard-compatible horizontal."

Question 3: "Do you operate mobile on 160? If so, what is the antenna used?" *Result:* Three used base-loaded verticals, eight used center-loaded ones, and one employed a Heliwhip. Some of the operators used capacitance hats. Other questions in the survey dealt with receiving antennas, types of soil and terrain, besides requesting complete details of the present transmitting antenna.

Fig. 34 shows some of the vertical systems used when the poll began in 1969. Additional configurations used by successful 160-meter operators are illustrated in Fig. 35. It can be seen that a great deal of useful "backyard theory" is represented in the systems shown. The experience and trials of others can save countless years of experimenting with antennas (not that some of us can't use the exercise)! It is hoped that these data will be of value to future 160-meter operators.

The Minooka Special

The following is a description of an effective vertical antenna for 160 meters, designed with these objectives in mind:

1) Highly effective for 160-meter DX and local work.
2) Easy to build and adjust.
3) Very economical.
4) Fits neatly into back yard.
5) Reasonable bandwidth.
6) Good for portable and DXpedition work.
7) Can be scaled down for mobile operation.

The resultant antenna (Fig. 36) is top loaded inductively and can be built by anyone from readily available material. Only a dip meter and SWR indicator are needed for tune-up. Many versions were built and tested, ranging from 7-foot (2.13-m) mobile types to 60-foot (18.29-m) backyard

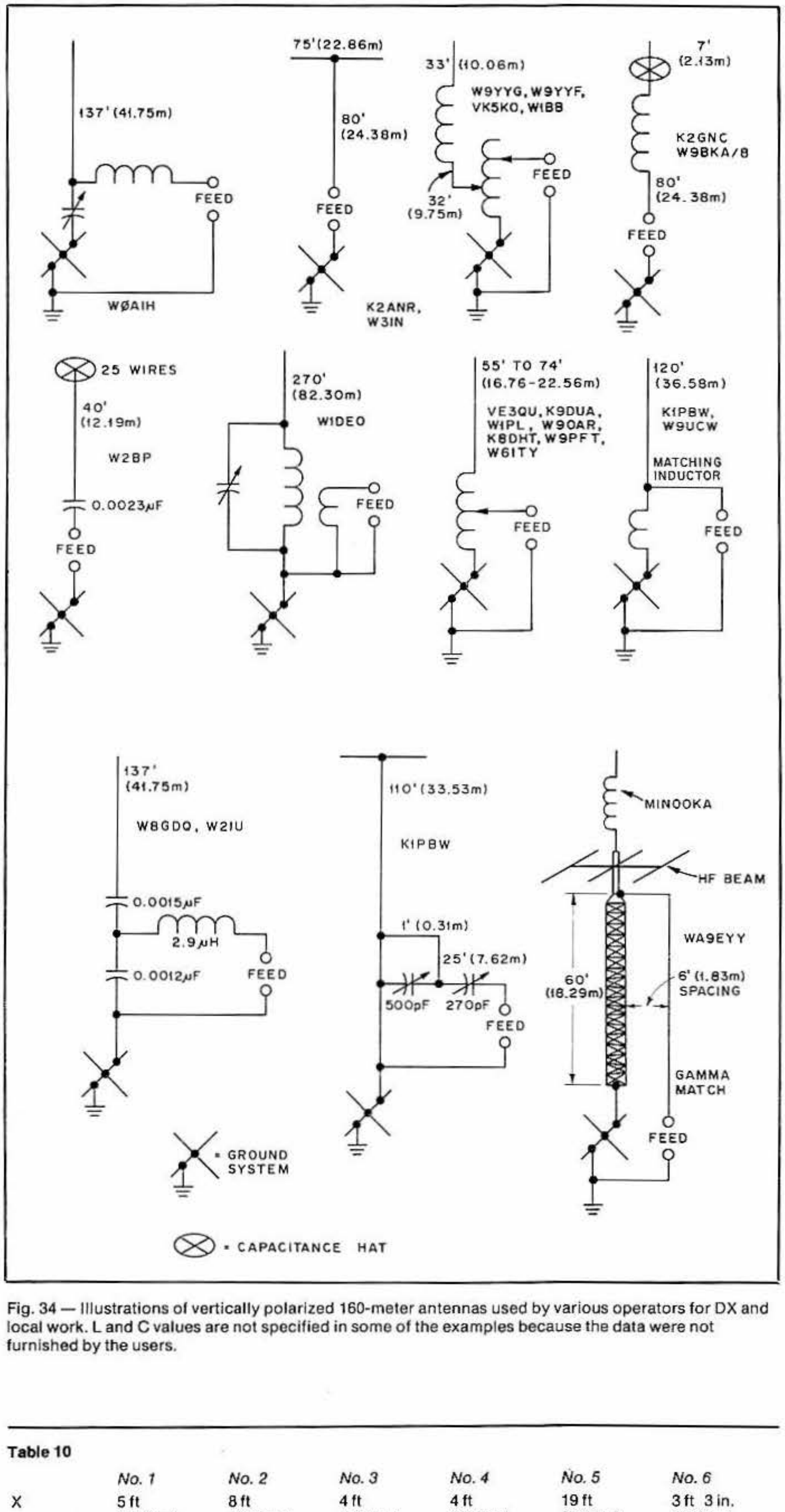


Fig. 34 — Illustrations of vertically polarized 160-meter antennas used by various operators for DX and local work. L and C values are not specified in some of the examples because the data were not furnished by the users.

Table 10

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
X	5 ft (1.52 m)	8 ft (2.43 m)	4 ft (1.22 m)	4 ft (1.22 m)	19 ft (5.79 m)	3 ft 3 in. (0.99 m)
Y	2 ft (0.61 m)	15 in. (381 mm)	3 ft 6 in. (1.07 m)	4 ft (1.22 m)	11 in. (279 mm)	3 ft (0.91 m)
Z	As long as possible					
Wire Size	No. 20	No. 19	No. 18	No. 16	No. 19	No. 22

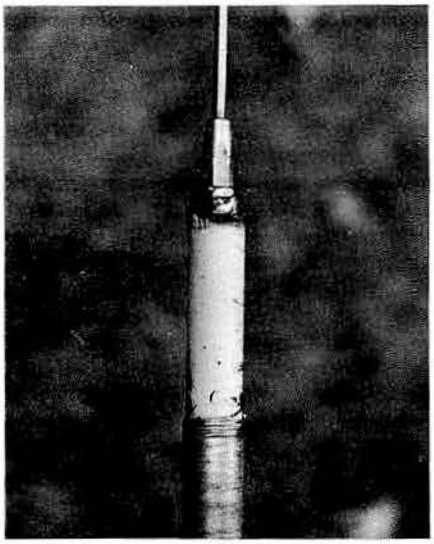
Here is a 50-foot (15.24-m) version of the Minooka Special. It is tuned remotely at K9SKX, and is used on 160 through 20 meters. Nylon or polypropylene guy lines should be used.

or DXpedition models. They have been used with good results from 20-foot (6.10-m)-wide backyards in cluttered Chicago, to vast beaches on Carribean islands, and in South America. The fixed-tuned bandwidths vary from 10 kHz for mobile versions, to 50 kHz for the larger fixed-station models (SWR 2:1 or better).

Construction

The physical layout of the antenna is centered around the use of 3/4-inch (19-mm) diameter rigid PVC water pipe. This sturdy tubing has an outside diameter of 1 inch (25 mm). The inner diameter provides an "interference fit" for 1/2-inch (13-mm) EMT conduit (thinwall). A 3/8-24 nut is driven into a 5-inch (127-mm) length of conduit, then aligned and braized into position. Next, the conduit is taper-ground and polished on the opposite end, then driven into the PVC tubing (see table of dimensions).

In the construction of mobile antennas another piece of conduit is driven into the bottom of the PVC coil form and a 3/8-24 bolt is brazed into the bottom end. The bolt will mate with standard mobile antenna mounts. For larger versions of the antenna the PVC material can be mounted in TV masting, or whatever. A standard 8-foot (2.44-m) stainless-steel whip between 3 and 8 feet (0.91 and 2.44 m) in length can be screwed into the top section. For home-installed versions of the antenna a



Close-up view of the top section of a coil assembly. This unit was used during mobile operation for over three years (40,000 miles or 64,374 km).

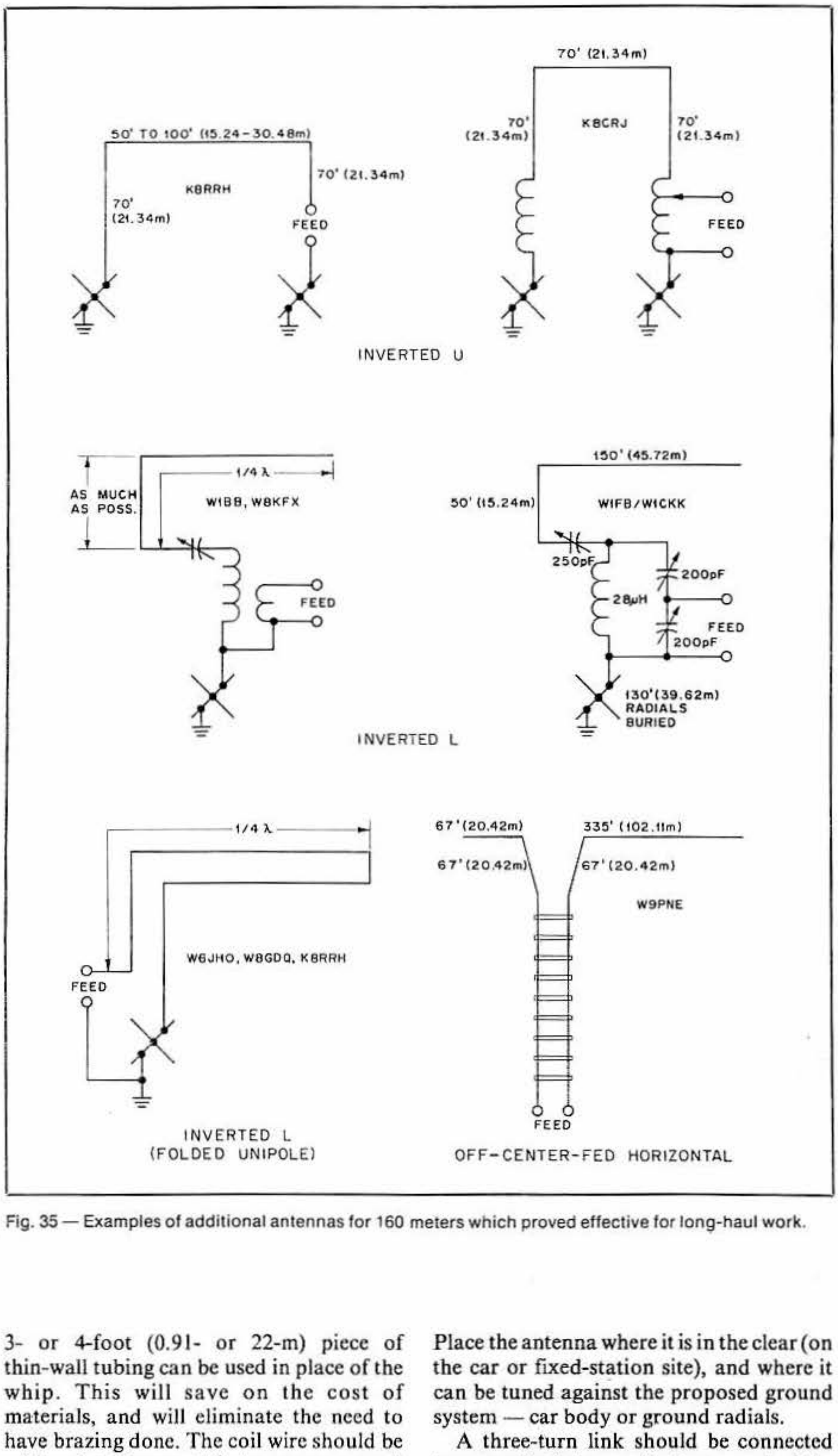
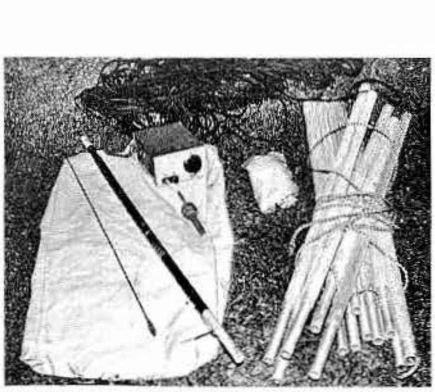


Fig. 35 — Examples of additional antennas for 160 meters which proved effective for long-haul work.

A mobile version of the Minooka Special is shown mounted on the author's car.



A portable version of the 160-meter vertical antenna. It was used by W9YYG and W9UCW at HK0BKX in January 1974.

3- or 4-foot (0.91- or 22-m) piece of thin-wall tubing can be used in place of the whip. This will save on the cost of materials, and will eliminate the need to have brazing done. The coil wire should be soldered to the conduit to assure a good electrical connection.

Adjustment

Pick a set of dimensions from the table which suits your application, but add a few inches more of coil turns (all turns close wound) than are recommended. This will allow leeway for pruning the system to resonance.

To simplify adjustment it is suggested that the system be assembled first with only the coil and top section (no base section). Place the antenna where it is in the clear (on the car or fixed-station site), and where it can be tuned against the proposed ground system — car body or ground radials.

A three-turn link should be connected temporarily between the lower end of the coil and the ground system. This will permit rough tuning of the system to resonance by inserting a dipper coil into the link and adjusting the coil turns on the antenna until a dip is noted in the desired part of the band. Upon completion of the pruning the constructor can, if he wishes, cover the coil with weatherproof tape or shrink tubing. The antenna should be tuned for roughly 2000 kHz if the entire band is to be used. Adjust the resonance for 1850 kHz if only the low segment will be utilized.

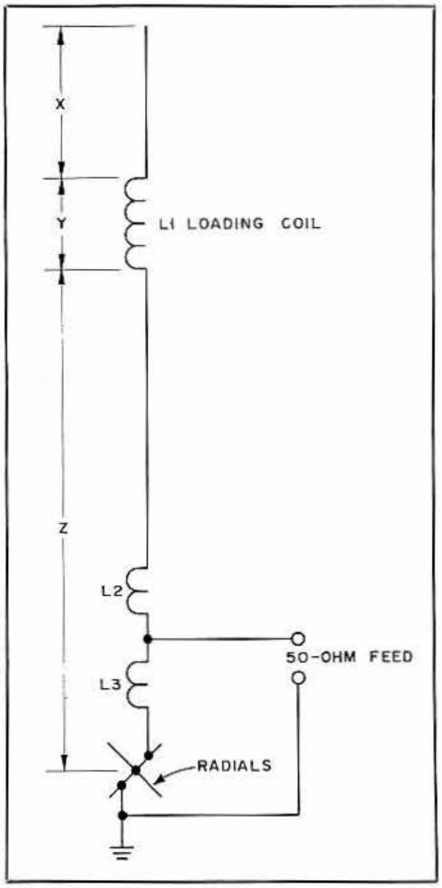


Fig. 36 — Electrical details of the Minooka Special. Table 10 gives specific information concerning dimensions X, Y and Z. L2 may vary in size from 1 to 20 turns, and L3 will contain between 5 and 10 turns, typically. L2 and L3 are made from no. 18 wire, spaced 1/8 inch (3 mm) between turns. The coil diameter is 1-1/2 inches (38 mm). Refer to text for tuning instructions.

Erect the antenna with all of its parts — coil, top and bottom section — and insert inductors L2 and L3 of Fig. 36 as shown. With L3 temporarily out of the system, adjust L2 for the lowerest value of SWR obtainable at the desired operating frequency. Then, place L3 back in the circuit and adjust it for an SWR reading of 1. Addition of the base section later on will not affect the resonant frequency of the overall system materially, provided the base section does not exceed, say, 60 feet (18.29 m).

The foregoing steps are used also in adjusting the mobile version of the antenna. However, because of the small size it is possible to adjust the antenna in completely assembled form. Only L3 of Fig. 36 is needed for mobile antennas. The main coil, L1, is adjusted for resonance, then L3 is set for lowest SWR. L3 can be mounted inside the trunk or under the bumper in a weatherproof enclosure.

For fixed-station operation it is recommended that a good ground system be employed. One should use at least 10 radials of, say, no. 18 or larger wire, 10 to 50 feet (3.05 to 15.24 m) in length. If you can manage 40 radials, 60 feet (18.29 m) in length, all the better.[1]

Concluding Comments

Three fixed-station versions of the Minooka Special have been tested and used at W9UCW. Each was compared against the regular antenna, which is a one-quarter wavelength vertical (130 feet [39.62 m] high), and operates against a radial system that contains 12,000 feet (3657.6 m) of wire. The short verticals were always inferior to the big antenna by approximately 5 dB.

Using version no. 4 from the table (4-foot [1.22-m] base section), the author worked W1s through W6s from the mobile setup. The rig was an HW-18 transceiver. Contacts were also made with VP9 and KV4 stations from the car.

While DXing from San Andres (HK0) reports were received of signal strengths exceeding S9 plus 20 dB from Maine to Washington. Good reports were received from Europe also.

Because the loading coil acts as an rf choke at 3.5 MHz and above, several versions of the antenna have been used successfully from 160 through 20 meters with an appropriate L-network matching section installed at the base of the system.

Acknowledgements

The author wishes to express his gratitude to all who helped make this article possible, . . . particularly K9SKX, WA9EYY, and W9YYF, who assisted with the initial experiments on the Minooka Special. The participants in the antenna survey (a list too large to include here) deserve considerable thanks for their help as well. This material was originally presented in *QST* by Barry A. Boothe, W9UCW.

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[1] [Editor's Note: The reader should be aware that 1/4-wavelength radials (or longer ones) are recommended for best efficiency in a system of this kind. Detailed information on the subject is given in *The ARRL Antenna Book*, 13th Edition. The recommendations given by the author are no doubt based on the lack of space available in the typical urban lot, around which his design was established. See Hills, "The Grounds Beneath Us." *RSGB Bulletin*, June 1966.]

Inexpensive 5/8-Wave Vertical Antenna with Coaxial Transformer

The author's hastily constructed 5/8-wave vertical antenna (inspired by W0JF's results[1]) consists of a supporting structure made from sections of 2 × 2-inch (51 × 51-mm) lumber on which four lengths of 300-ohm TV ribbon are affixed. Each section of ribbon line is 41 feet 6 inches (12.65 m) long. A length of this line is attached to each side surface of the 2 × 2 support mast, then the ends (top and bottom) of all four line sections are connected in parallel to form a single vertical conductor. The coax-line dimensions are near those of W2JTJ,[2] and are shown in Fig. 37. The SWR varies from a flicker of reflected power at 14,000 kHz to 1.5:1 at 14,350 kHz. (The next task is to get that lowest-SWR point shifted to 14,275 kHz.) The whole thing is leaning against a tree, almost vertical, and seems to work well. This material was originally presented in *QST* by Robert J. Earl, W1DRV.

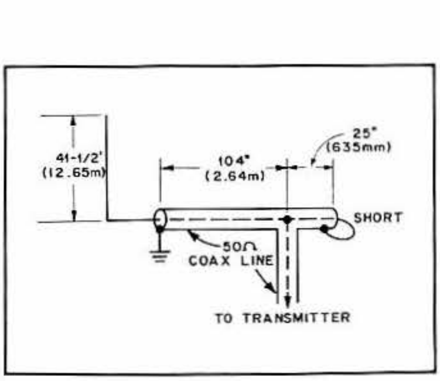


Fig. 37 — Coax-line transformer for 20-meter 5/8-wave vertical antenna.

References

[1] Beers, "Short Antennas for the Lower Frequencies," *QST*, August and September 1970.

[2] Czerwinski, "Coaxial Transformer for Voltage-Fed Antennas," *QST*, June 1961.

A Backyard 160-Meter Vertical

A 160-meter band was the favorite one at the author's QTH this winter. The same could be said for many other amateurs and the simple antenna described here may be of interest.

Some of the old-timers will tell the newcomer to 160 meters that the best antenna for local and DX work is the vertical. Since a full-size vertical would be very large, the question is finding a type that will fit into a closely packed residential area.

As a starter, the writer took an old 40-foot (12.19-m) telescoping mast and insulated it from the ground. (This can be done by setting it on top of a large soft-drink bottle, or clamping it to a wooden post.) The antenna was fed at the base with RG-58A/U 52-ohm coaxial cable. The shield was wired to a radial system and a ground rod. A hint for the radials — buy some aluminum clothesline and cut a number of slits in your yard with a flat spade. Next, push the wire into the slits and tamp the grass back together. If there are any swampy parts of the yard, these seem to make the best ground areas.

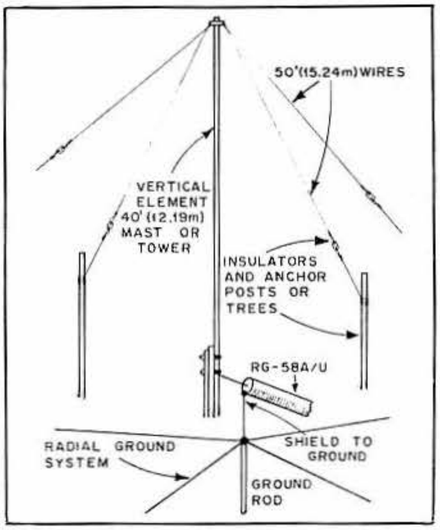

50'(15.24m)WIRES
VERTICAL ELEMENT 40' (12.19m) MAST OR TOWER
INSULATORS AND ANCHOR POSTS OR TREES
RG-58A/U
RADIAL GROUND SYSTEM
SHIELD TO GROUND
GROUND ROD

Fig. 38 — A space-saving vertical for 160 meters. While not always possible, it is desirable to have the wires for the top hat run off at right angles to the mast.

Rather than using a loading network at the base of the antenna, the author constructed a capacitive hat to load it at the top instead. The top hat was made from four 50-foot (15.24-m) pieces of wire strung out from the top of the mast in guy-wire fashion. They are connected electrically to the top, and stretched until they are as close as possible to a 90-degree angle with respect to the mast.

The system described works well with a 40-foot (12.19-m) mast, but other lengths could be used instead. However, the top hat may have to be adjusted in order to bring the system to resonance. While my vertical occupies very little space, it seems to perform as well as do many "full-size" antennas on 160 meters. This material was originally presented in *QST* by Mike Mussler, WB8JJA.

Chapter 2

Yagi Antennas

The antenna systems treated in this chapter are variations of the basic directional gain antenna devised many years ago by Yagi and Uda. Over the years the fundamental design and its variations have been referred to simply as the Yagi. How Mr. Uda was excluded from the credits remains a mystery, as he was a co-developer of the antenna under discussion.

Yagi types of antennas appeal to all manner of hf- vhf- and uhf-band operators. The primary response characteristic of the Yagi is unidirectional, discounting minor response lobes off the front, sides and rear of the antenna. The major lobe concentrates the radiated energy in a desired direction to provide gain in dB and discrimination against interference from unwanted directions.

Yagis can be used singly or in array combinations. In the latter case, each time the size of an array is doubled the system gain can be made to increase by 3 dB — assuming that the phasing, impedance matching, and aperture parameters are correct. Thus, a pair of 3-element Yagis which are "stacked" in an array to meet the foregoing criteria will exhibit 3 dB more gain than a single 3-element Yagi. To effect another 3 dB increase in gain, four 3-element Yagis would need to be placed in a given array of Yagis, and so on.

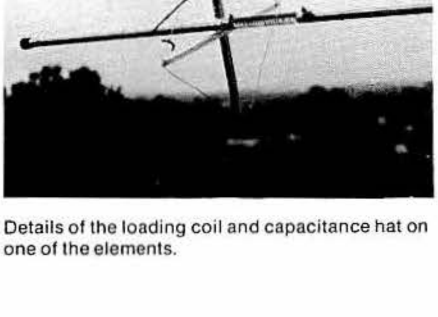
This chapter deals with the cream of the Yagi crop, so to speak, as taken from past issues of *QST*. When zoning laws and available property permit, the Yagi is preferred over the single-element vertical antennas described in chapter 1.

The 20-Meter DX Weasel

Short antennas have always captured the interest of amateurs.

The antenna presented here is a monoband version of the Bite-Size Beam for 20 and 15 meters published elsewhere in this chapter. It is designed for 20-meter operation only. Most of the parts were "lifted" from the original array.

The reader is cautioned against attempting to figure why some of the dimensions were selected. As a point of interest, they just happened that way. One new twist was added to this system — capacitance hats. The hats provided one noticeable improvement in performance which became obvious during the initial tune-up phase of the project. The hats lowered the Q of the elements and hence broadened the overall response of the system. While only conjecture, one might say that it is this broad tuning which causes the parasitic elements to perform as they do. Element tuning on the Bite-Size Beam[1] was critical. If the dimensions given here are followed carefully, the antenna should provide excellent characteristics for gain and pattern. Front-to-back measurements indicate approximately 20 dB. The front-to-side ratio was measured in excess of 25 dB. There are no objectionable side lobes. The SWR is less than 2:1 at each end of the band when the gamma capacitor and rod are set for proper operation at 14.1 MHz. There is no need to select phone or cw as the primary mode of operation.



Details of the loading coil and capacitance hat on one of the elements.

Construction

The boom and all the elements are made from 1-1/4-inch (32-mm) diameter aluminum tubing available at most hardware stores. The two boom sections and the two pieces which make up the center portion of the driven element are coupled using 15-inch (0.38-m) sleeves of 1-3/8-inch (35-mm) OD aluminum tubing. Sheet-metal screws should be used to secure the sections within the coupling sleeves.

The loading coils are wound on 1-1/8-inch (29-mm) diameter Plexiglas rod. Details are shown in Fig. 1. Be sure to slit the ends of the aluminum tubing where the compression clamps are placed. The coils are made from no. 14 enameled wire. The specified number of turns are equally spaced to cover the entire 9 inches (229 mm) of Plexiglas.

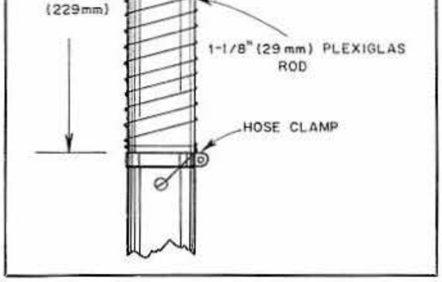


Fig. 1 — Details for joining sections of aluminum tubing and Plexiglas rod.

The capacitance hats are constructed from 3/4-inch (19-mm) angle aluminum. Two pieces 2 feet (0.61 m) in length are required for each hat. The model shown in the diagrams has the angle aluminum

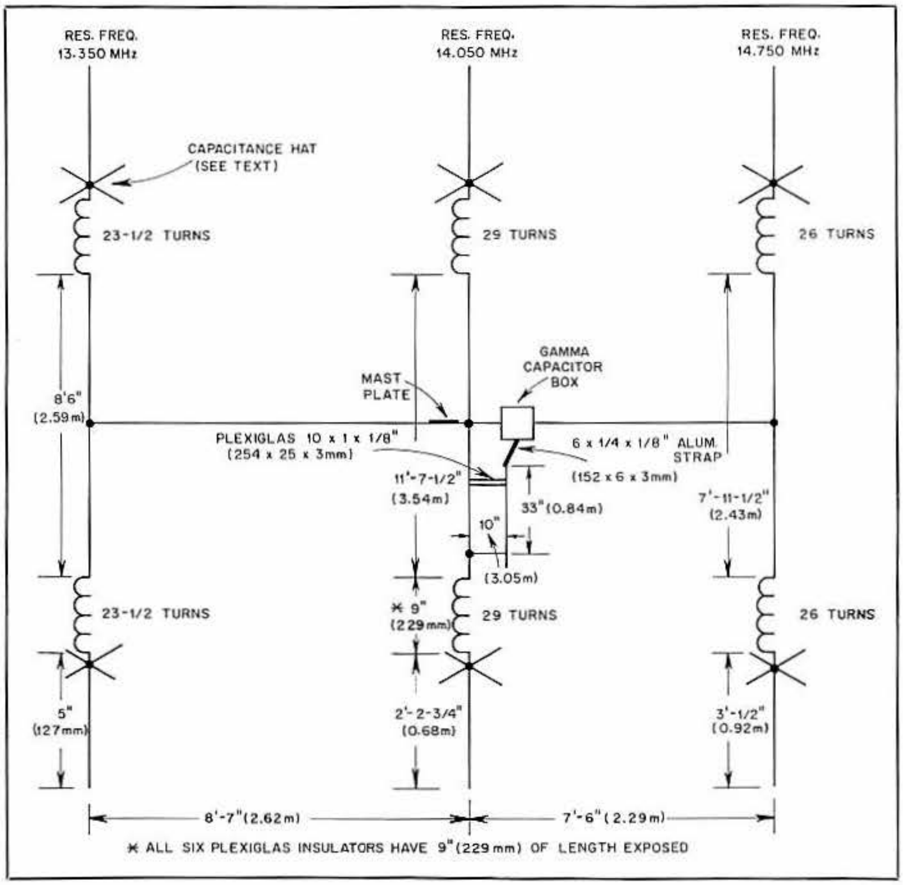


Fig. 2 — Constructional details for the 20-meter beam. The coils on each side of the element are identical. The gamma capacitor is a 140-pF variable unit manufactured by E. F. Johnson Co.

Table 1

Complete Parts List for the Short Beam

Qty	*Material*
2	10-foot (3.05-m) lengths of 1-1/4-inch (32-mm) dia. aluminum tubing (one for the reflector center section, one for the reflector end sections).
3	8-foot (2.44-m) lengths of 1-1/4-inch (32-mm) dia. aluminum tubing (two lengths for the boom, one length for the director element center).
4	6-foot (1.83-m) lengths of 1-1/4-inch (32-mm) dia. aluminum tubing (two lengths for the driven element center, two lengths for the director and driven element ends).
2	15-inch (0.38-m) lengths of 1-5/8-inch (41-mm) dia. aluminum tubing.
1	40-inch (12.19-m) length of 1-3/8-inch (10-mm) dia. aluminum tubing.
4	6-foot (1.83-m) lengths of 3/4-inch (19-mm) angle aluminum.
6	12-inch (0.31-m) lengths of 1-1/8-inch (29-mm) dia. Plexiglas rod.
1	9-inch (229-mm) square, 1/4-inch (6-mm) thick aluminum plate.
8	U bolts.
12	Compression hose clamps.
8	Crutch caps.
38 ft	No. 12 enameled copper wire.
60 ft	No. 14 enameled copper wire.

fastened to the element using aluminum strips and no. 8 sheet-metal screws, but sheet-metal screws alone can be used. Solder lugs are fastened to the ends of the angle aluminum and no. 12 or 14 wire connects the ends of the aluminum, resulting in a square loop. The wires should be soldered at each of the solder lugs.

All of the elements are secured to the boom with TV U-bolt hardware. Plated bolts are desirable to prevent rust from forming. An aluminum plate 9 inches (229 mm) square by 1/4-inch (6-mm) thick was used as the boom-to-mast plate.

A boom strut is recommended because the weight of the elements is sufficient to cause the boom to sag. A 1/8-inch (3-mm) diameter nylon line is plenty strong. A U-bolt clamp is placed on the mast several feet above the antenna and provides the attachment point for the center of the truss line. To reduce the possibility of water accumulating in the element tubing and subsequently freezing, crutch caps are placed over the ends. Rubber feet suitable for keeping furniture from scratching hardwood floors would serve the same purpose.

A piece of Plexiglas was mounted inside an aluminum Minibox to provide support and insulation for the gamma capacitor. A plastic refrigerator box would serve the purpose just as well. The capacitor housing is mounted to the boom by means of a U bolt. The gamma rod is made of 3/8-inch (10-mm) aluminum 40 inches (1.016 m) long and is connected to the gamma capacitor by a 6-inch (152-mm) length of strap aluminum.

Tune-Up and Operation

The builder is encouraged to follow the dimensions given in Fig. 2 as a starting point for the position of the gamma rod shorting strap. Connect the coaxial cable and install the antenna near or at the top of the tower. The gamma capacitor should be adjusted for minimum SWR at 14.1 MHz as indicated by an SWR meter (or power meter) connected in the feed line at the gamma capacitor box. If a perfect match cannot be obtained, a slight repositioning of the gamma short might be required.

Evaluation of performance is always a difficult task. The 20-Meter DX Weasel is mounted on top of a 50-foot (15.24-m) high tower at the QTH of W1FB. The transmitter input power for the testing period was 3 watts. Many European stations as well as a ZL have been contacted with ease. In fact, the Weasel has been responsible for cracking a few pileups on the first call!

Obtaining the Material

Table 1 lists all of the major parts used in the 20-meter Weasel. Most of the U-bolt hardware as well as the aluminum tubing should be available from large hardware stores. The Plexiglas rod, however, presents a bit more of a problem as indicated by mail received by the ARRL Technical Department. Many large plastic supply dealers stock the cast rod. The problem is that there are not very many large dealers! Additionally, Plexiglas is a petroleum-base product which means the cost is no doubt higher than one would expect. Those amateurs who are unable to locate aluminum hardware or Plexiglas should consult the yellow pages to see who their nearest supplier is. This material was originally presented in *QST* by Robert Myers, W1XT and Jay Rusgrove, W1VD.

[1] See page 45.

The HW-40 Micro Beam

A helically wound 2-element 40-meter Yagi.

Disconsolate pleas from apartment dwellers and other amateurs who live on property that is too small in area to permit the use of large 40-meter antennas prompted the authors to develop the antenna described here. The particular dimensions represented in this design were dictated primarily by the kind of fiberglass tubing that was immediately available. Kirk quad spreaders were obtained for use as forms on which to wind the helical elements. Longer (or shorter) elements can be used with good results. This article is intended as a guide in the design of similar antennas.

The HW-40 is scaled down to 28 percent of full size. Two elements are used, each being 18 feet (5.49 m) in length, tip-to-tip. Thus, the elements are just 2 feet (0.61 m) longer than those of a full-size 10-meter Yagi. A 16-foot (4.88-m)-long Reynolds aluminum-tubing boom (two 8-foot [2.44-m] lengths joined) provides 0.12-wavelength spacing between the driven element and reflector. The weight of the array is approximately 25 pounds, making it practical to use a TV-type antenna rotator with the system.

Design Considerations

Some may argue that helically wound antennas will tend to radiate off the ends of the elements (axial mode), and that the condition will prevent the Yagi from exhibiting normal front-to-side and front-to-back characteristics. It was established by Kraus,[1] that axial-mode radiation occurs only when a helix is one wavelength or greater in circumference. Generally, when the circumference is less than two-thirds wavelength, a nearly sinusoidal type of current distribution exists. This is effected by alternate reinforcement and cancellation of the two traveling waves which are directed oppositely. Each is of nearly identical current amplitude (I_O), hence the T_O transmission mode results for both traveling waves on the helix. Because of the foregoing condition the helices of this antenna radiate in the *normal mode* and will exhibit linear polarization characteristics. The diameter of these helices is merely 0.0009469 wavelength, eliminating any opportunity for axial-mode radiation. Front-to-side and front-to-back checks of the beam indicate, indeed, that normal-mode radiation is occurring. A number of relative tests were performed locally at distances up to 20 miles, and the front-to-back characteristics indicate a 10-dB figure. Front-to-side checks confirm a figure of approximately 28 dB. The effect is not so pronounced when receiving high-angle incoming signals. Depending upon the time of day, distance involved, and other propagation factors, various directivity traits will be observed.

The HW-40 beam, just 28 percent of full-size, is light enough to require only a TV-rotator.

Helically wound elements were chosen in preference to lumped-inductance elements in order to obtain linear voltage and current distribution across the elements, and to make the matching technique less difficult. Even if end-loaded elements with capacitance hats were used, the 18-foot (5.49-m) dimension would make it impossible to use a gamma match of conventional design. Because of the very low value of radiation resistance of short loaded antennas, other conventional matching schemes would not lend ease to matching a 50-ohm coaxial feeder to the system.

There are certain penalties one must accept when using physically shortened antennas of this kind, and an in-depth treatment of the subject was given by Sevick in *QST*.[2] It was a fortunate circumstance in this case that the feed-point impedance of the beam turned out to be approximately 12 ohms. Therefore, a 4:1 toroidal balun was installed at the feed point to provide a near-perfect match to the 50-ohm transmission line. In addition to encountering low values of feed impedance, the bandwidth of loaded elements is greatly less than with full-size antennas. This beam was tuned for operation at a center frequency of 7050 kHz. It works well from 7025 to 7075 kHz, with an SWR no greater than 2:1. It is flat at 7050 kHz. Those wishing to duplicate this Yagi should be willing to accept this design trade-off in the interest of having an effective directional antenna. It is recommended, therefore, that it be tuned for one's favorite part of the 40-meter band. The use of a Transmatch will, however, permit excursions into portions of the band where the SWR becomes greater than 1:1.

Construction Details

The construction of the 40-meter beam is very simple and requires no special tools or hardware. Two fiberglass 15-meter quad arm spreaders are mounted on an aluminum plate with U bolts, as shown in the photograph. A wooden dowel is inserted approximately 6 inches (152 mm) in the end of each fiberglass arm to prevent the U bolts from crushing the poles. The aluminum mounting plate is equipped with U-bolt hardware for attachment to the 1-1/4-inch (32-mm) diameter boom.

A plastic refrigerator box is mounted on each element support plate and is used to house a Miniductor coil. No. 14 copper wire is used for the elements. The wire is wound directly on the fiberglass poles at a density of *40 turns per foot* (not turns per inch!) for a total of 360 evenly spaced turns. The wire is attached at each end with an automotive hose clamp of the proper size to fit the fiberglass rods. Since the fiberglass is tapered, care must be taken to keep the turns from sliding in the direction of the tips. Several pieces of plastic electrical tape were wrapped around the pole and wire at intervals of 1 foot (0.31 m). All of the element half sections are identical in terms of wire and pitch. Coil dimensions and type are given in Fig. 3.

The driven-element matching system consists of a 4:1 balun transformer and a link tightly coupled to the Miniductor. Complete details are given in Fig. 4.

Mounted at the end of each element (held in place by the hose clamp) is a short section of stiff copper wire used to allow for final tuning of the system as well as to broaden the frequency response of the antenna. Since the overall antenna is very small in relation to a full-sized array, the SWR points of 2:1 are rather close to each other, as mentioned earlier. The antenna shown in the photograph provides an SWR of less than 2:1 within about 25 kHz either side of resonance. Tuning the antenna for phone-band operation should not be difficult and the procedure outlined below should be suitable.

Tuning

The parasitic element is adjusted to be about four percent lower in frequency than

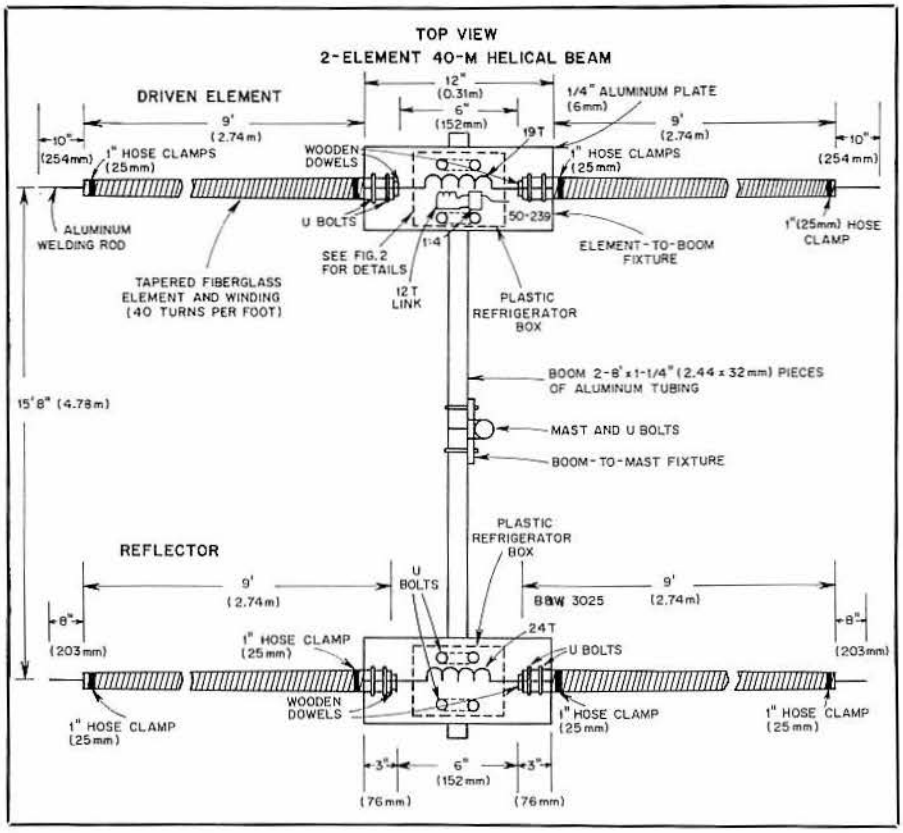


Fig. 3 — Overall dimensions for the 40-meter short beam. The boom consists of two pieces of standard 1-1/4-inch (32-mm) dia do-it-yourself aluminum tubing.

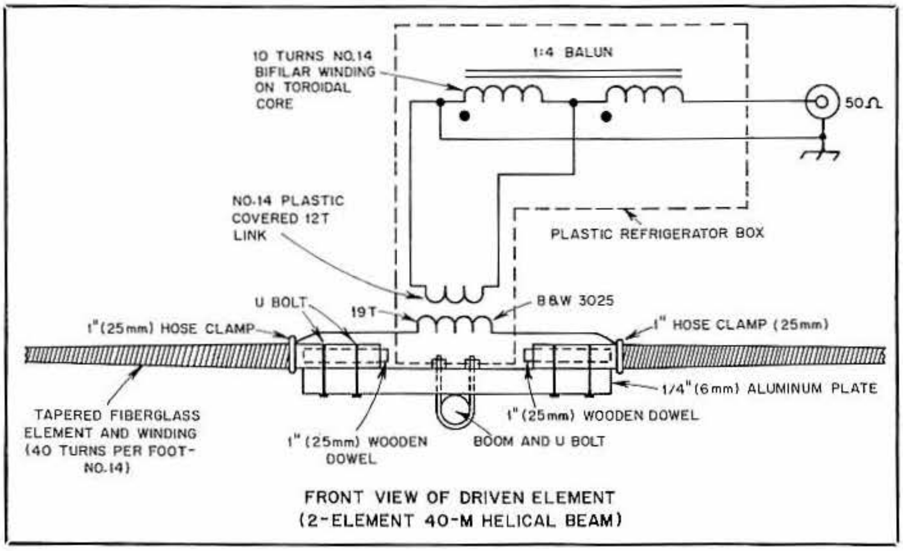

10 TURNS NO.14 BIFILAR WINDING ON TOROIDAL CORE
1:4 BALUN
50Ω
NO.14 PLASTIC COVERED 12T LINK
PLASTIC REFRIGERATOR BOX
U BOLT
19T
B&W 3025
1"(25mm) HOSE CLAMP
1" HOSE CLAMP (25mm)
1/4"(6mm) ALUMINUM PLATE
TAPERED FIBERGLASS ELEMENT AND WINDING (40 TURNS PER FOOT-NO.14)
1"(25mm) WOODEN DOWEL
1"(25mm) WOODEN DOWEL
BOOM AND U BOLT
FRONT VIEW OF DRIVEN ELEMENT
(2-ELEMENT 40-M HELICAL BEAM)

Fig. 4 — Schematic diagram of the balun assembly mounted inside the plastic utility box. The core is a single T-200-2 Amidon. The 12-turn link is wound directly over the 19-turn Miniductor.

the driven element. A grid-dip oscillator was coupled to the center loading coil and the element tips were trimmed (a quarter of an inch [6 mm] at a time!) until the GDO indicated resonance to be at 6.678 MHz. For phone-band use, the ends could be snipped for 6.840 MHz. Adjusting the driven element is simple. Place an SWR meter or power meter at the input connector and cut the end wires (or add some if necessary) to obtain a proper match between line and antenna.

Performance Characteristics

Once the initial near-ground tuning of the elements was completed, the HW-40 was carried aloft and mounted on the 40-foot (12.19-m) tower at W1FB. Final touching up of the matching and element resonances was effected after the beam was in place on the tower. It is important to realize that shortened antennas are sensitive to changes in environment because of their narrow-band characteristics. Thus, height above ground and distance from nearby objects will cause some change in resonance of the elements. The resonant frequency of the HW-40 changed some 150 kHz between tuning at several feet above ground to final tweaking atop the tower.

It should be noted that the 40-meter beam has yet to be tested at an ideal height above ground. A distance of 40 feet (12.19 m) above the earth is not much more than one-quarter wavelength at 7 MHz, though performance thus far has been better than one might expect when using a beam or dipole less than one-half wavelength above ground.

Comparisons were made between the beam and three types of wire antennas . . . an inverted V, a 3/4-wavelength end-fed wire, and a full-wave 40-meter loop (with its theoretical 2-dB gain).[3] The results have been interesting, though at times rather confusing. The confusion results from the time-of-day/propagation syndrome mentioned earlier. At no time, however, did the inverted-V or 3/4-wavelength antennas surpass the performance of the HW-40. The beam was always as good as or better than the other two radiators, regardless of band conditions or time. During contacts with European or South American DX stations, the beam was always the best antenna, usually by two S units or more. During daytime contacts out to, say, 1000 miles, the wire antennas equalled the beam at times.

When comparing the beam to the full-wave loop, results became less easy to evaluate. That is, the antennas took turns being best. Frequently, the loop outperformed the beam (in the favored direction of the loop) both on short-haul and DX contacts. At other times the beam had the edge by a couple of S units. At this time it is impossible to say which antenna would provide the best all-year, all-around service. But, it has been observed that the beam is far less subject to pickup of man-made and atmospheric noise because of its narrow-band characteristics (the loop exhibits the opposite bandwidth trait— broad). Reduction in noise during reception can be a blessing, especially when working with the weaker signals! Another beneficial effect of the narrow-band feature is that strong, near-frequency signals do not so severely affect the receiver with respect to overloading and cross modulation, as is the situation with other types of antennas. The proof of this came when trying to operate while W1AW (two blocks away from W1FB) was transmitting code practice. Until the beam was erected it was impossible to use the 40-meter band, but with the beam connected to the receiver, and with the antenna pointed away from W1AW, it became possible to operate within 10 kHz of W1AW without knowing that station was on the air! So, if some kW operator lives down the street from you, this little beam could put you back in business.

While running approximately 80 watts output, the short beam has been extremely effective in working DX. DX stations now answer our CQs, whereas with the wire antennas (loop excepted) this seldom happened. Signal reports from DX stations average 579, with many 589 and 599 reports. During QRP operation with the beam (2 watts output), a number of DX stations have been raised and worked. The signal reports are lower of course, but RST 559 and 569 indicates that something good must be happening! One unrelated event occurred while testing the beam and loop with the QRP setup: a station in the 4th call area called CQ and was answered. He came back and said, "No QRP lids, CQ kWs only." It's unlikely that the HW-40 beam can be blamed for that, especially since we went on to work five European stations later that day with the 2-watt equipment!

Acknowledgements

The authors wish to express gratitude to those who helped construct, test and erect the 40-meter beam. Special thanks to K1JX, who "clomped" up and down the ARRL test tower and the W1FB station tower numerous times with test gear (and the beam) until the final design goals were met. Thanks also to W1NPG (SK) who labored silently while winding the helices, and subsequently endured the unbearable Connecticut heat-wave temperatures of August, while putting two coats of exterior spar varnish on the completed elements. The element dimensions and turns information were developed by K1TD to test a newly developed calculator program. This material was originally presented in *QST* by Robert Myers, W1XT and Doug DeMaw, W1FB.

References

[1] Kraus, *Antennas*, First Edition, McGraw-Hill Book Co., Chapter 7.

[2] Sevick, "The Ground-Mounted Short Vertical," *QST*, March 1973, p. 13. (See Chapter 1.)

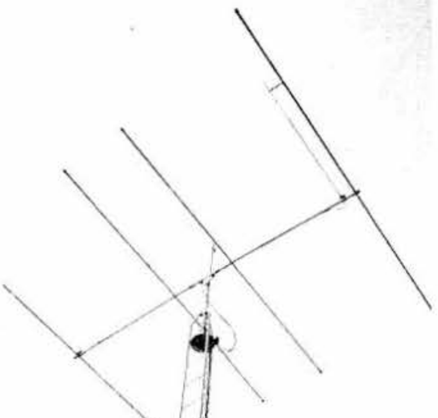
[3] DeMaw, "The Novi-Loop," *QST*, October 1973. (See Chapter 4.)

A Bite-Size Beam for 20 and 15 Meters

Do you want to work DX from your space-restricted QTH with increased effectiveness? If the answer is yes, perhaps this two-band Yagi system is just the one for you.

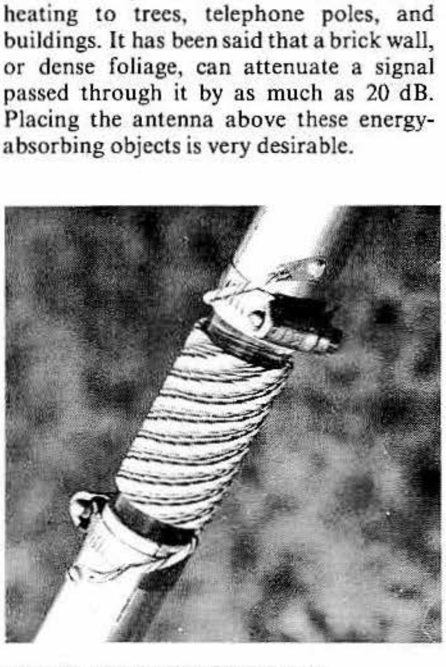
There is no doubt that a hundred-foot (30.48-m) tower with stacked monobanders for 20 and 15 meters is one way to generate an effective signal in the pileups. But what are the characteristics of this big system which make it perform better than a dipole strung between two trees? First, the tall tower places the antenna up in the clear, away from most of the surrounding ground clutter. Even a relatively short tower (40-foot [12.2-m] variety) provides this advantage in many instances. The ability to point the major radiation lobe of the antenna in the correct direction is another reason the high monobanders outperform the kinky wire. But if the antenna is capable of supporting its own elements, the directional characteristics can be used to good advantage whether the beam is mounted at 100 feet (30.5 m), or at 40 feet (12.2 m). And without any question, the ability to reject interference aids substantially in the reception of weak signals.

A typical one-foot (0.31-m)-per-side triangle tower is self-supporting (when properly installed) to 40 feet in height and requires less than one square foot of property. For many amateurs, the major limiting factor is the inability to turn a monoband beam (or even a large tribander) without hitting some object like a tall tree. Hesitation on behalf of the amateur to place what might be considered by his neighbors an offensive amount of hardware in the sky near his home is another reason beams are ruled out. The 2-element-per-band, 20- and 15-meter, interlaced Yagi presented here, overcomes these problems. It is lightweight and is less than 16-feet (4.88-m) square. And it's probably no more obtrusive than a large TV antenna.



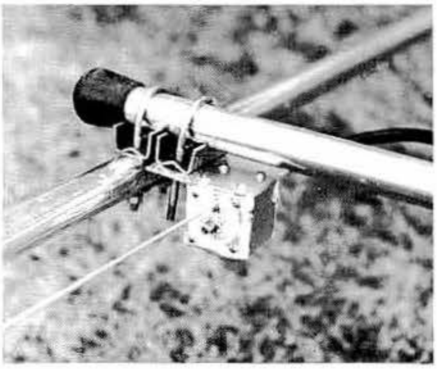
So What if It's Short!

A popular misconception among amateurs is that any element short of full size is no good in an antenna system. Reducing the size of an antenna by 50 percent does lower the efficiency by a decibel or two, but the gain capability of a parasitic array outweighs this small loss in efficiency. Mounting the antenna above the interference-generating neighborhood can greatly reduce susceptibility to man-made noise and certainly aids in the reduction of rf heating to trees, telephone poles, and buildings. It has been said that a brick wall, or dense foliage, can attenuate a signal passed through it by as much as 20 dB. Placing the antenna above these energy-absorbing objects is very desirable.



The coils are wound on Plexiglas rod. Compression clamps are used to hold the Plexiglas in position Sheet-metal screws and solder lugs provide attachment points for the ends of the loading coils.

View of the short beam from the front yard at W1FB.



The gamma assembly is held in place by means of a small U bolt. The capacitors are mounted on etched circuit board.

It is a generally accepted fact that traps are difficult to build and adjust, as well as their being lossy. Loading coils, on the other hand, are easy to wind and require essentially no adjustment. If the wire size is large, losses are not a major factor. W2FMI lauded the merits of short antennas in an earlier article explaining that in reality, short (50 percent) elements do not materially depreciate the gain.[1] With these ideas in mind, the authors designed and built a shortened-element, but wide spaced, director array for 20 meters interlaced with a similar 15-meter reflector configuration also having optimum spacing for maximum gain. By placing the 15-meter driven element in front of the 20-meter array, the longer 20-meter elements tend to act as reflectors on 15 meters. There are no unwanted reflectors "in front" nor any directors "behind" the active array — elements which could cause pattern distortion and poor front-to-back ratio.

Construction

The dual-band beam has four elements, the longest of which is 16 feet (4.88 m). All of the elements and the boom are made from 1-1/4-inch (32-mm) diameter aluminum tubing available at most hardware stores. Element sections and boom pieces are joined together by slotting a 10-inch (254-mm) length of 1-1/4-inch (32-mm) tubing with a nibbling tool and compressing it for a snug fit inside the element and boom tubing. Coupling details are shown in Fig. 6.

The loading coils are wound on 1-1/8-inch (29-mm) diameter Plexiglas rod. The rod slips into the element tubing and is held in place with compression clamps. Be sure to slit the end of the aluminum where the compression clamps are placed. The model shown in the photographs has coils made of surplus Teflon-insulated miniature audio coaxial cable with the shield braid and inner conductor shorted together. A suitable substitute would be no. 14 enameled copper wire wound to the same dimensions as those given in Fig. 5.

All of the elements are secured to the boom with common TV U-bolt hardware. Plated bolts are desirable to prevent rust from forming. A 1/4-inch (6-mm) thick boom-to-mast plate is constructed from a few pieces of sheet aluminum cut into 10-inch (254-mm) square sheets and held together with no. 8 hardware. Several cookie tins could be used if sheet aluminum is not available. One local amateur used a plate from a large electrical box as a boom-to-mast bracket. Since it is galvanized, it is quite resistant to the harsh New England winters.

A boom strut (sometimes called a truss) is recommended because the weight of the elements is sufficient to cause the boom to sag a bit. A 1/8-inch (3-mm) diameter nylon line is plenty strong. A U-bolt clamp is

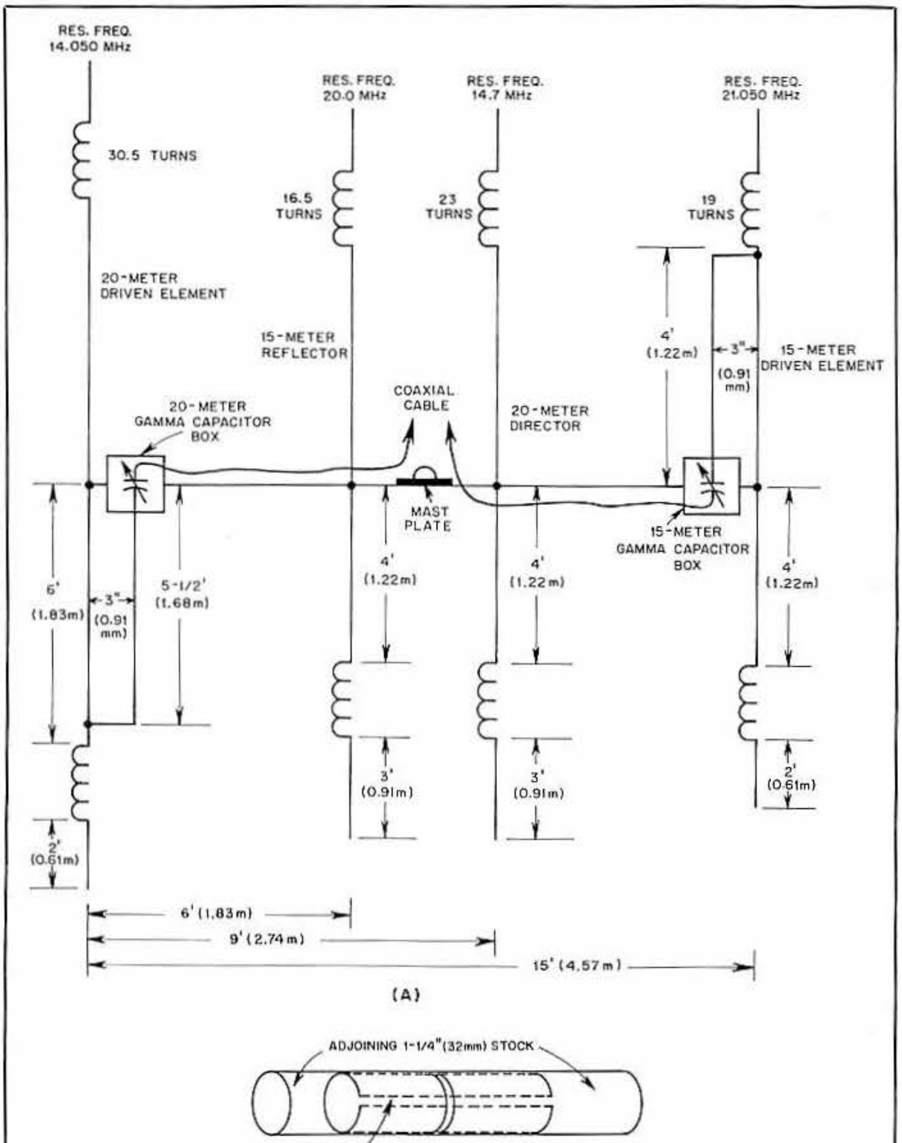
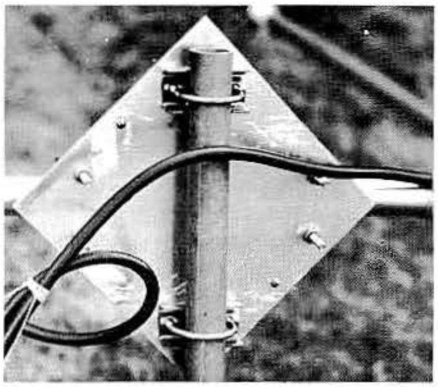


Fig. 5 — Constructional details for the 20- and 15-meter beam. The coils for each side of the element are identical. The gamma capacitors are each 140-pF variable units manufactured by E. F. Johnson Co. The capacitors are insulated from ground within the container. Since the design is one-half size for each band, the tuning is somewhat critical. The builder is encouraged to follow carefully the dimensions given in the text.

Table 2

Complete Parts List for the Short Beam

Qty	*Material*
9	8-foot (2.44-m) lengths of aluminum tubing, 1-1/4-in. (32 mm) dia
11	U bolts
2	Variable capacitors, 140 pF (E. F. Johnson)
4 ft	Plexiglas cast rod, 1-1/8-in. (29 mm) dia
16	Stainless steel hose clamps, 1-1/2-in. (38 mm) dia
1	Aluminum plate, 8-in. (203 mm) square
10 ft	Aluminum solid rod, 1/4-in. (6 mm) dia
2	Refrigerator boxes, 4 X 4 X 4 in. (102 X 102 X 102 mm)
25 ft	Nylon rope, 1/8-in. (3 mm) dia
16	No. 8 sheet metal screws
16	No. 8 solder lugs
8	Plastic (or rubber) end caps, 1-1/4-in. (32 mm) dia



The boom-to-mast plate.

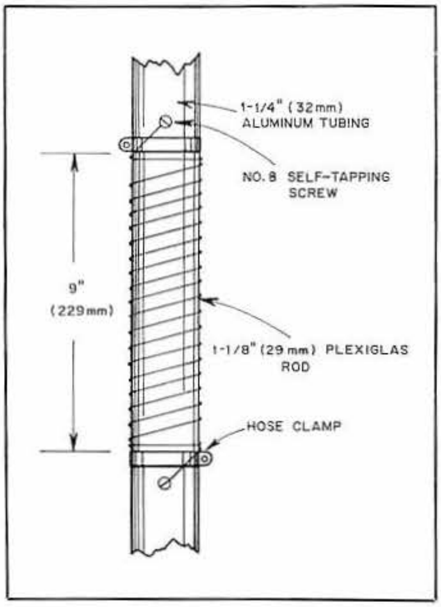


Fig. 6 — Coupling details for joining sections of aluminum tubing.

placed on the mast several feet above the antenna and provides the attachment point for the center of the truss line. To reduce the possibility of water accumulating in the element tubing and subsequently freezing (rupture may be the end result), crutch caps are placed over the element ends. Rubber feet suitable for keeping furniture from scratching hardwood floors would serve the same purpose. In fact, the rubber tips prevent the element ends from damaging surrounding objects during installation.

A heavy-duty steel mast should be used, such as a 1-inch (25-mm)-diameter galvanized water pipe. Steel TV mast is also acceptable. Any conventional TV-type antenna rotator should hold up under load conditions presented by this antenna. Nevertheless, certain precautions should be taken to assure continued trouble-free service. For instance, whenever possible, mount the rotator inside the tower and extend the mast through the tower top sleeve. This procedure relieves the rotator from having to handle lateral pressures during windy weather conditions. A thrust bearing is desirable to reduce downward forces on the rotator bearings.

Hookup and Operation

The monoband nature of the beam requires the use of two coaxial feed lines. The coaxial cable is attached to the 15-meter element (at the front of the beam) at the gamma-capacitor box. The other end of the cable is connected to a surplus 28-V dc single-pole coaxial switch.[2] The cable for the 20-meter element is connected in a similar fashion. The switch allows the use of a single feed line from the shack to a point just below the antenna where the switch is mounted. It is a simple matter to provide voltage to the switch for operation on one of the two bands. At the price of coaxial cable today, a double run of feed line represents a substantial investment and should be avoided if possible.

An etched-circuit board was mounted inside an aluminum Minibox to provide support and insulation for each of the gamma tuning capacitors. Plastic refrigerator boxes available from most department stores would serve just as well. The capacitor housing is mounted to the boom by means of U bolts.

The builder is encouraged to follow the dimensions given in Fig. 5 as a starting point for the position of the gamma rods and shorting bar. Placing the antenna near the top of the tower and then tilting it to allow the capacitors to be reached makes it possible to adjust the capacitors for minimum SWR as indicated by an SWR meter (or power meter) connected in the feed line at the relay. If the SWR cannot be reduced below some nominal figure of approximately 1.4:1, a slight repositioning of the gamma short might be required. The dimensions given are for operation at 14.050 MHz and 21.050 MHz. The SWR climbs above 2:1 about 50 kHz in either direction from the center frequency. Although tests were not conducted at more than 150 watts input to the transmitter there is no reason why the system would not operate correctly with a kilowatt of power supplied to it.

After many months of testing at the QTH of W1FB, several characteristics were noted. First, the antenna withstood several wind and ice storms common to Connecticut. Performance turned out to be what can be expected from a 2-element Yagi. Since the 20-meter portion of the antenna is a director array, the front-to-back ratio is a bit less than 10 dB. On 15 meters, where the system operates with a reflector parasitic element, the front-to-back ratio is considerably better — on the order of 15 dB.

This antenna was mounted atop a 40-foot (12.2-m) tower where previously there was connected a 20-meter sloping dipole pointed at Europe (a multielement array for 2 meters graced the top of the tower!). The number of European stations contacted increased rather dramatically with the installation of the beam. Except in pileups on rare DX stations, DX is now worked as a routine, even though W1FB is a QRP fan and typically runs less than 2 watts of output power.

No doubt the increased effectiveness of the signal was caused by several factors. The antenna certainly has gain (although at ARRL hq. we have no way of making accurate measurements) and is well above the nearby small trees. More importantly, the antenna is now far from the aluminum house siding which once was directly in the pattern of the 20-meter "sloper." Of course, the front-to-back characteristic has the tendency of making DX signals louder in relation to stateside stations and therefore makes receiving much easier.

If previously you've felt that a beam and tower were not possible at your QTH, perhaps re-evaluation of the situation is in order. This antenna, as shown in the photograph, does not appear offensive when viewed from the front yard. Yet the overall amount of property occupied (at ground level) is less than one square foot. And the turning radius is slightly over 11 feet (3.35 m)! This material was originally presented in *QST* by Robert Myers, W1XT and Clarke Greene, K1JX.

References

[1] Sevick, "The W2FMI Ground-Mounted Short Vertical," *QST*, March 1973. (See Chapter 1.)

[2] Purchased from Fair Radio Sales, Lima, OH.

Linear Loaded 20-Meter Beam

Build this novel minibeam for 20 meters . . . it works!

Full-sized antennas are fine if you have the height and room for them. But much of the advantage is usually lost with average installations. So why bother with a sad-looking monster a few feet atop the house when a trim, smaller model will do the job. This article deals with a method that eliminates the messy and expensive loading coils as well.

Having built an HW-32A transceiver, the author's 20-meter activity was restricted to the phone band. A homemade vertical antenna did a fair job in the states, but not for DX. This writer's thoughts ran to a beam and the aluminum tubing that could be obtained for full-size construction. A 2-element beam was constructed, using a gamma match and information found in the *Handbook*. The beam worked electrically, but the mechanical construction left much to be desired. It flopped in the wind like a wounded butterfly. The author tried to correct this with a wooden framework, but it was just as bad. Something with shorter elements was desired, something that was rigid and would still perform well. But all of the author's research turned up only loading coils or other methods involving a loss compromise.

The author's aluminum supply included four 12-ft (3.66-m) lengths of 7/8-inch (22-mm) diameter tubing. This would give two elements of 24 ft (7.32-m) length and a minimum of sag. The problem was how to mount them and make up the difference in physical and electrical length for a half-wave length. Loading coils were ruled out. The possibility of folding wire under the elements seemed to have merit. (Later, this was found to be called linear loading.) This dictated a split element and standoff supports for the tubing.

Two 2-ft (0.61-m) lengths of aluminum channel were obtained for the element supports (Fig. 7). each 12-ft (3.66-m) section was attached using 1-in. (25-mm) ceramic standoff insulators. A 34-in. (19-mm) birch dowel was used to stiffen and prevent crushing of the tubing where the attachment was made. Element supports were grooved and attached to a 10-ft (3-m) TV mast section using a single 5/16-in. (8-mm) U bolt.

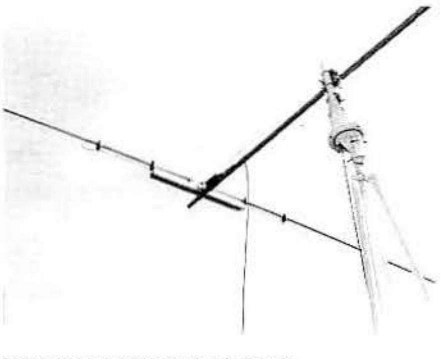
The folded additional loading wire was no. 12 copper house wire with the insulation stripped off, and was supported by two bakelite blocks on each element section. The blocks were anchored to the tubing by small sheet metal screws. Ends of the wire sections were formed into a loop to hold their position.

Tune-Up and Adjustments

My thinking in regard to coaxial-cable-fed dipoles is that they should use a balun or matching device of some kind. This beam, having a split driven element, seemed to call for a 1:1 balun since it was to be fed with RG-58/U (Fig. 8). Formulas found in handbooks for beam-element lengths did not seem to work for the linear-loading design, so cut-and-try was used many times. In final tests, a grid-dip meter was utilized with a calibrated receiver to determine the driven-element total length of 35 ft (10.67 m). A reflector with 10-ft (3.05-m) spacing was used.

It was found that adding a reflector of five-percent greater length lowered the frequency (with the beam near the ground) but on raising the beam to rooftop, the frequency had increased. The 10-ft spacing gave a 3:1 VSWR which was very difficult to reduce. Testing this arrangement on the air seemed to indicate more gain in the back direction than in the front. After many tests and much rebuilding of the wire lengths, the director element approach seemed to give the most encouraging results. The VSWR was down to 1.5:1 and the five-percent shorter director raised the frequency to the phone band. Spacing was reduced to 7 ft 6 in. (2.29 m).

More research brought out the possibility of inductive matching to get the VSWR



The beam atop the author's tower.

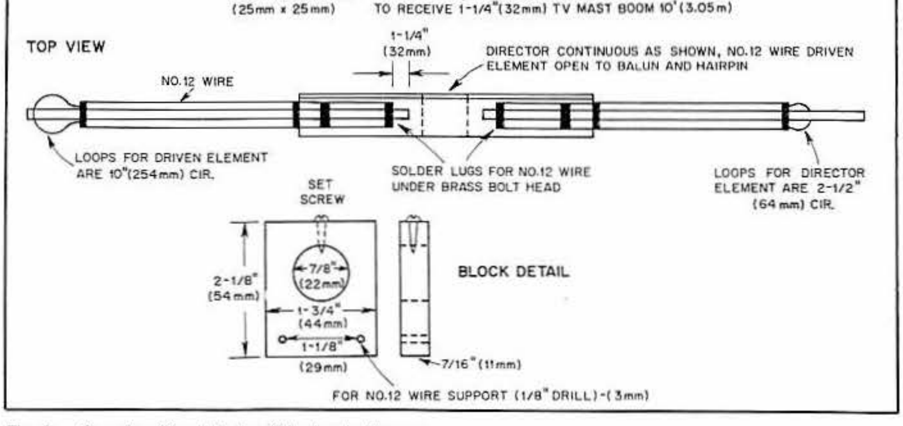
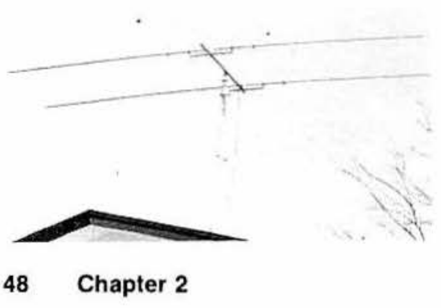

SIDE VIEW
11'6" x 7/8" DIRECTOR (3.50m x 22mm)
12' x 7/8" DRIVEN ELEMENT (3.66m x 22mm)
1-1/2" (38mm)
BAKELITE BLOCK
BRASS BOLTS
5-1/2" (140mm)
15" (381mm)
NO.12 FOLDED WIRE
1/8" (3mm) ALUMINUM CHANNEL
2' x 2" x 2" (61m x 51mm x 51mm)
1" x 1" INSULATOR (25mm x 25mm)
5/16" (7mm) U BOLT
TO RECEIVE 1-1/4" (32mm) TV MAST BOOM 10' (3.05m)
TOP VIEW
1-1/4" (32mm)
DIRECTOR CONTINUOUS AS SHOWN, NO.12 WIRE DRIVEN ELEMENT OPEN TO BALUN AND HAIRPIN
NO.12 WIRE
LOOPS FOR DRIVEN ELEMENT ARE 10" (254mm) CIR.
SOLDER LUGS FOR NO.12 WIRE UNDER BRASS BOLT HEAD
LOOPS FOR DIRECTOR ELEMENT ARE 2-1/2" (64 mm) CIR.
SET SCREW
2-1/8" (54mm)
7/8" (22mm)
1-3/4" (44mm)
1-1/8" (29mm)
BLOCK DETAIL
7/16" (11mm)
FOR NO.12 WIRE SUPPORT (1/8" DRILL)-(3mm)

Fig. 7 — Construction details of the loaded beam.



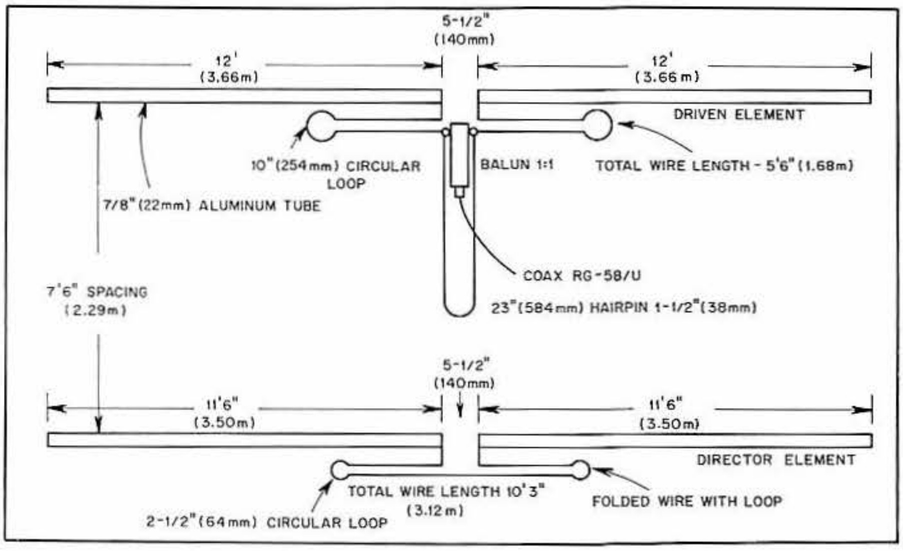


Fig. 8 — Critical electrical dimensions.

down to a more reasonable level. Many hairpin lengths and widths were tried with varying results. The final hairpin was 23-in. long by 1-1/2 in. (580 × 38 mm) wide with a slight fan shape to fit the balun connections. This reduced the VSWR at 14,200 kHz and 14,350 kHz with a flat response in between.

On-the-Air Tests

The help of other amateurs in tests for front-to back ratio was very helpful. Average reports have been 2.5 S units in the forward position over the back position. The author did not have a reference dipole for gain tests, but has heard and worked more DX than in the past 20 years. The beam is mounted on a rooftop 10-ft (3-m) steel tower 38 ft (11.6-m) above the ground. It weighs around 20 pounds and is rotated by an older-type TV rotator. This material was originally presented in *QST* by Cole Collinge, W0YNF.

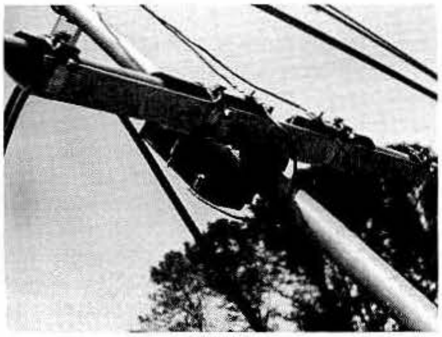
The Log-Yag Array

The Yagi antenna array has been around for years and years. A relative newcomer to hams is the log-periodic dipole array (LPDA), which offers nearly constant gain over a greater bandwidth than the Yagi. Guess what happens when you cross a Yagi with an LPDA . . . .

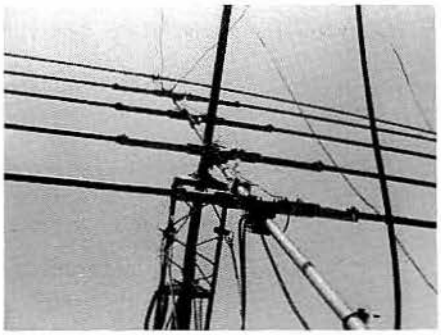
With the decline in sunspot activity, a number of amateurs have considered monoband Yagi arrays. The first problem encountered seems to be array length, that is, overall size for a desired gain and bandwidth. The Log-Yag principle, as will be discussed shortly, has produced a system which will provide the amateur with another alternative to the long-boom Yagi, stacked Yagis, or loop-antenna systems. The L-P Yagi (Log-Yag) array is not a new system; many such arrays have been designed and developed by Oliver Swan[1] and others.[2] This article, however, will provide the basic theory of operation, design procedure, and the construction of a practical antenna.

Theory of Operation

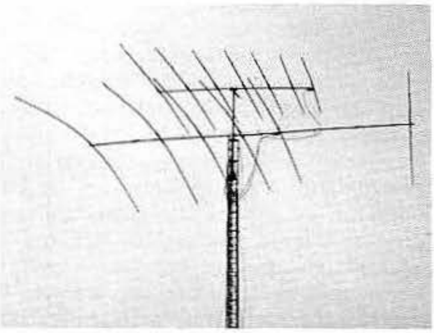
The Log-Yag array utilizes an LPDA-driven[3] group of elements, designed to cover a desired bandwidth, in conjunction with parasitic elements to achieve higher gains and greater directivity than would be realized with either the LPDA or Yagi array alone. The Yagi array requires a long boom and wide element spacing for wide bandwidth and high gain. This is because the Q of the Yagi system increases as the number of elements is increased and/or as the spacing between adjacent elements is decreased.[4,5] An increase in the Q of the Yagi array means that the total bandwidth of that array is decreased; optimum gain, front-to-back ratio, and side lobe rejection are obtainable only over small portions of the band. Dr. I. L. Morris, using a high-speed digital computer, has completed extensive research on 4-, 8-, and 10-director Yagi-Uda arrays.[6] His work is comprehensive and is recommended reading for all technically minded amateurs. The parameters varied in his study were element length, spacing, radius and number. As can be seen in Fig. 9, the forward gain and front-to-back ratio



The attachment of the elements to the boom.



From the front to the back of the Log-Yag array. Note the truss provides lateral and vertical support.



The completed Log-Yag array ready for use. The array mounted above the Log-Yag is a 7-element LPDA for 21 to 30 MHz.

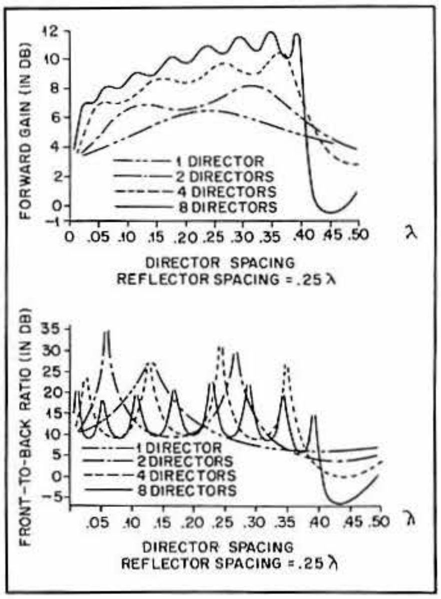
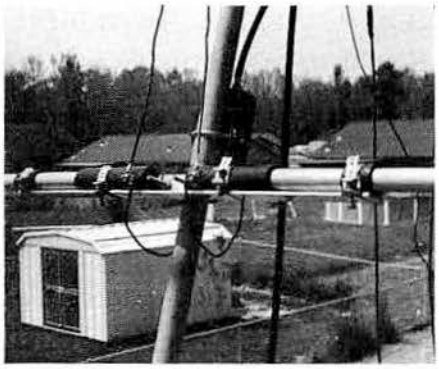


Fig. 9 — The effects of director spacing on various Yagi arrays. The change in gain and front-to-back ratio is plotted for the change in director spacing. The reflector spacing has been held constant.



The connections between the balun and the input terminals.

deteriorate sharply as element spacings decrease. If the elements are closely spaced, then as the frequency is shifted either side of the array design frequency the electrical spacing between adjacent elements changes rapidly. This causes a higher SWR and a deterioration of forward gain and front-to-back ratio.

The Log-Yag system overcomes this difficulty by using a multiple driven element "cell" designed in accordance with the principles of the log-periodic dipole array.[7,8] Since this log cell exhibits both gain and directivity by itself, it is a more effective radiator than a simple dipole driven element. The front-to-back ratio and gain of the log cell can be improved with the addition of a parasitic reflector and director. It is not necessary for the parasitic element spacings to be large with respect to wavelength, as in the Yagi array, since the log cell is the determining factor in the array bandwidth. In fact, the element spacings within the log cell may be small with respect to a wavelength without appreciable deterioration of the cell gain. For example, decreasing the relative spacing constant (σ) from 0.1 to 0.5 λ will decrease the gain by less than 1 dB. Hence, a further reduction in boom length. It can be seen that the Log-Yag array will exhibit high theoretical gain (11 dBd), high front-to-back ratio (30 dB), high cross polarization (front-to-side ratio —45 dB), and a wideband response utilizing boom lengths approximately one half that of a Yagi with similar characteristics.[2]

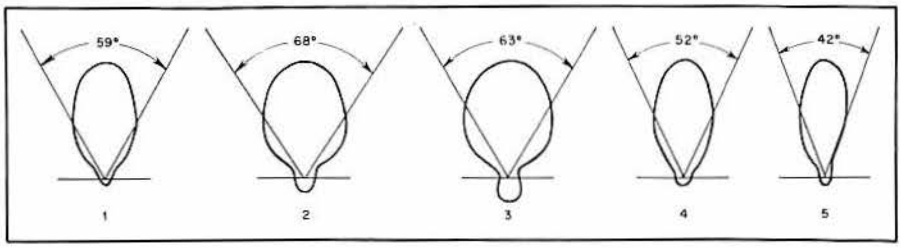


Fig. 10 — Beam patterns of 20-meter arrays.
No. 1 — 3-el. log cell, dir. @ 0.1λ, ref. @ 0.2λ.
No. 2 — 5-el. log periodic, σ = 0.1.
No. 3 — 3-el. log cell, 1st dir. @ 0.1λ, 2nd dir. @ 0.2λ.
No. 4 — 4-el. log cell, ref. @ 0.15λ.
No. 5 — 4-el. log cell, dir. @ 0.15λ, ref. @ 0.085λ (described in this article).

The author has built many monoband 14-MHz Log-Yag arrays in an attempt to find an optimum combination of elements, while holding the boom length to that of a full-sized, three-element monobander Yagi. Relative radiation patterns for various element combinations are found in Fig. 10. The final array design takes the form of a four-element log cell, parasitic reflector spaced at 0.085 λ_{max} and parasitic director spaced at 0.15 λ_{max} where λ_{max} is the longest free-space wavelength within the array passband. It has been found that array gain is almost unaffected with reflector spacings from 0.08 λ to 0.25 λ and the increase in boom length is not justified.[9] The function of the reflector is to improve the front-to-back ratio of the log cell while the director sharpens the forward lobe and decreases the half-power beamwidth. As the spacing between the parasitic elements and the log cell decreases, the parasitic elements must increase in length.[10]

The log cell is designed to meet upper and lower band limits with $\sigma = 0.05\lambda$. The design parameter τ is dependent on the structure bandwidth, B_s. When the log-periodic design parameters have been found, the element length and spacings can be determined. A review of the "Log-Periodic Dipole Array" is recommended though not necessary for the design of the Log-Yag array.[3,7,8]

The method of feeding the antenna is identical to that of feeding the log-periodic dipole array without the parasitic elements. As shown in Fig. 11, a balanced feeder is required for each log-cell element, and all adjacent elements are fed with a 180° phase shift by alternating connections. Since the Log-Yag array will be covering a relatively small bandwidth, the radiation resistance of the narrow-band log cell will vary from 80 to 90 ohms (tubing elements) depending on the operating bandwidth. The addition of parasitic elements lowers the log-cell radiation resistance. Hence, it is recommended that a 1-to-1 balun be connected at the log-cell input terminals and 52-ohm coaxial cable be used for the feed line. The measured radiation resistance of the 14-MHz Log-Yag installed at the author's QTH is 37 ohms, 14.0 to 14.35 MHz. It is assumed that tubing elements will be used. However, if a wire array is used then the radiation resistance R_o and antenna-feeder input impedance Z_o must be calculated so that the proper balun and coax may be used. The procedure is outlined in detail in *The ARRL Antenna Book.*[3,7]

Design Procedure

The following step-by-step design procedure may be used to design any monoband Log-Yag for any desired bandwidth.

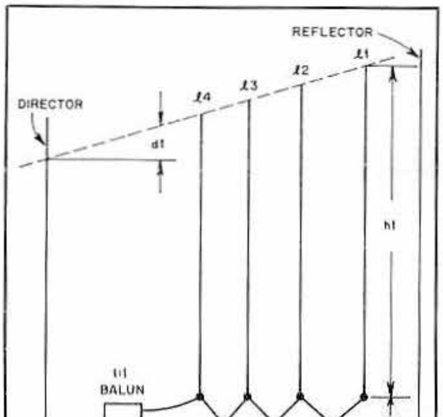


Fig. 11 — Layout of the Log-Yag array.

1) Determine the operating bandwidth, B, between f_1, lowest frequency (band edge), and f_n, highest frequency (band edge).

$$B = \frac{f_n}{f_1}$$

2) Determine the structure bandwidth (log-cell array) B_s.

$$B_s = 1.15B$$

3) Determine the design parameter τ (based on 4-element log cell, note 1).

$$\tau = \frac{1}{\sqrt[3]{B_s}}$$

Note 1. The design parameter τ is chosen for a four-element log cell since it provides the best bandpass for most amateur bands. For log cells with any number of elements

$$\tau = \frac{1}{\sqrt[(n-1)]{B_s}}$$

where n = number of elements within the log cell.

4) Determine the apex half-angle α: Since $\sigma = 0.05$ (relative spacing constant), then

$$\cot\alpha = \frac{0.2}{1-\tau}$$

5) Determine the longest free-space wavelength λ_{max}, log-cell boom length, L (ft) and longest element length within the log cell l_1 (ft).

$$\lambda_{max} = \frac{984}{f_1 \text{MHz}}$$

$$L = \left[\frac{1}{4}\left(1 - \frac{1}{B_s}\right)\cot\alpha\right]\lambda_{max}$$

and

$$l_1 = \frac{492}{f_1 \text{MHz}}$$

$$l_2 = \tau l_1$$

$$l_3 = \tau l_2$$

$$l_4 = \tau l_3$$

6) Determine the element spacing (d_{12}), distance between elements l_1 and l_2 (ft).

$$d_{12} = \frac{1}{2}\left(l_1 - l_2\right) \quad \cot\alpha$$

and

$$d_{23} = \tau d_{12}$$

$$d_{34} = \tau d_{23}$$

7) Determine the parasitic element lengths (ft) and spacings (ft).

$$l_{REF} = \frac{509.6}{f_1 \text{ MHz}}$$

$$d_{REF} = \frac{84}{f_1 \text{ MHz}}$$

$$l_{DIR} = \frac{450.8}{f_1 \text{ MHz}}$$

$$d_{DIR} = \frac{148}{f_1 \text{ MHz}}$$

This completes the design.

The Finished Log-Yag

The proof is always to be found in the completed and operating product. The

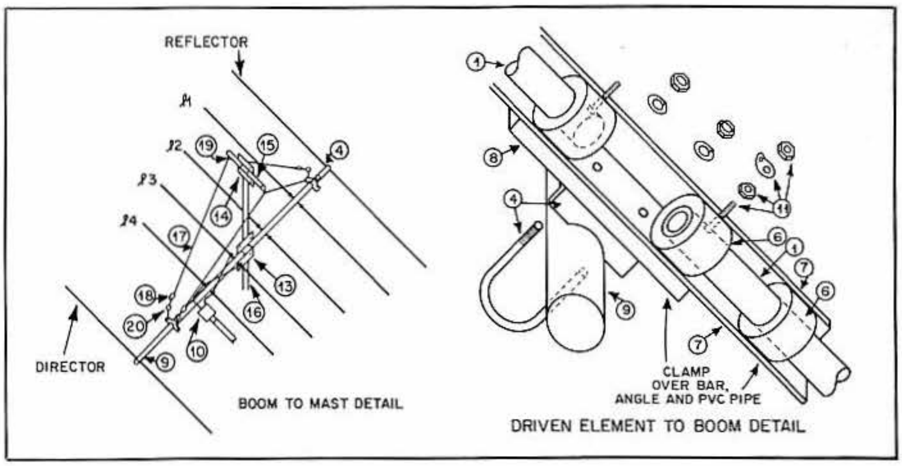
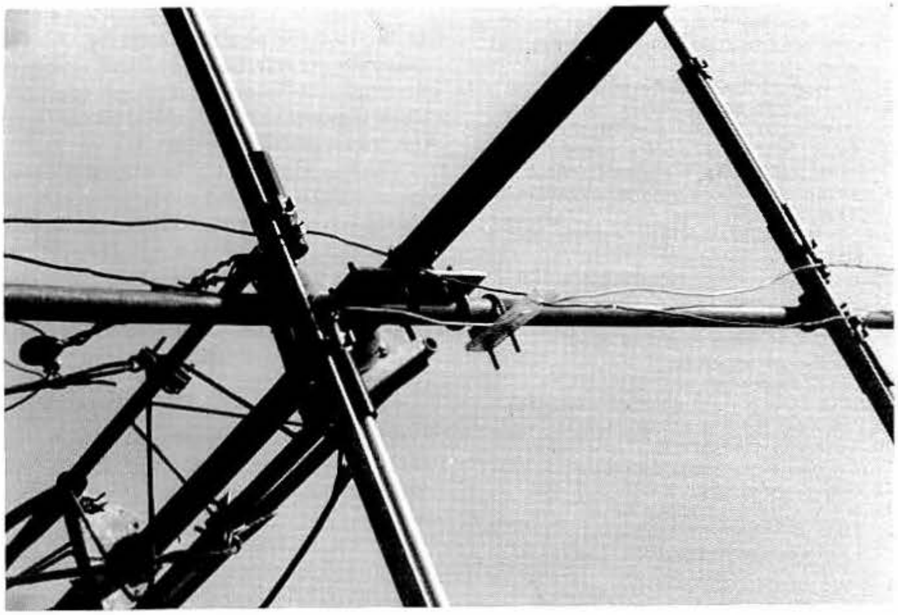


Fig. 12 — Assembly details. The numbered components refer to Table 6.



The interconnection between the elements of the log cell changes sides between each element.

Table 3

Array Characteristics

1. Frequency range	14–14.35 MHz
2. Operating bandwidth	B = 1.025
3. Design parameter	$\tau = 0.946657$
4. Apex half angle	a = 14.92°, cot = 3.753
5. Half-power beam width	42° (14-14.35 MHz)
6. Bandwidth of structure	$B_s = 1.17875$
7. Free-space wavelength	$\lambda_{max} = 70.28$ ft
8. Log cell boom length	L = 10.0 ft
9. Longest log element	$l_1 = 35.14$ ft (a tabulation of element lengths and spacings given in Table 2)
10. Forward gain over dipole	11.5 dB (theoretical)
11. Front-to-back ratio	32 dB (theoretical)
12. Front-to-side ratio	45 dB (theoretical)
13. Input impedance	$Z_0 = 37$ ohms
14. SWR	1.3 to 1 (14-14.35 MHz)
15. Total weight	96 pounds
16. Wind-load area	8.5 sq. ft
17. Feed-point impedance	$Z_0 = 37$ ohms
18. Reflector length	36.4 ft @ 6.0 ft spacing
19. Director length	32.2 ft @ 10.5 ft spacing
20. Total boom length	26.5 ft

The mechanical construction of the log cell is identical to that described in *The ARRL Antenna Book*, except for the lengths and spacings.[3,7] Fig. 12 shows how the log cell is constructed as well as the addition of the parasitic elements.

1 ft = 0.30478 m

Table 4

Array Dimensions

Element	*Length Ft*	*Spacing Ft*
Reflector	36.4	6.0 (Ref. to l_1)
l_1	35.14	3.51 (d_{12})
l_2	33.27	3.32 (d_{23})
l_3	31.49	3.14 (d_{34})
l_4	29.81	10.57 (l_4 to dir.)
Director	32.2	

1 ft = 0.30478 m

Table 5

Element Material Requirements

Element	*1-in. Tubing Length (Ft)*	*Qty.*	*7/8-in. Tubing Length (Ft)*	*Qty.*	*3/4-in. Tubing Length (Ft)*	*Qty.*	*1 1/4-in. Angle Length (Ft)*	*1 X 1/4-in. Bar Length (Ft)*
Reflector	12	1	6	2	8	2	None	None
l_1	6	2	6	2	8	2	3	1
l_2	6	2	6	2	8	2	3	1
l_3	6	2	6	2	6	2	3	1
l_4	6	2	6	2	6	2	3	1
Director	12	1	6	2	6	2	None	None

1 ft = 0.30478 m

Table 6

Materials List

1. Aluminum tubing — 0.047 in. wall thickness
   1 in. — 12 ft lengths, 24 lin. ft
   1 in. — 12 ft or 6 ft lengths, 48 lin. ft
   7/8 in. — 12 ft or 6 ft lengths, 72 lin. ft
   3/4 in. — 8 ft lengths, 48 lin. ft
   3/4 in. — 6 ft lengths, 36 lin. ft
2. Stainless steel hose clamps — 2 in. max., 8 ea.
3. Stainless steel hose clamps — 1-1/4 in. max., 24 ea.
4. TV-type U bolts — 1-1/2 in., 6 ea.
5. U bolts, galv. type: 5/16 in. X 1-1/2 in., 4 ea.
6. U bolts, galv. type: 1/4 in. X 1 in., 2 ea.
7. 1 in. ID water-service polyethylene pipe 160 lb/in.^{2} test, approx. 1-3/8 in. OD, 7 lin. ft
8. 1-1/4 in. X 1-1/4 in. X 1/8 in. aluminum angle — 6 ft lengths, 12 lin. ft
9. 1 in. X 1/4 in. aluminum bar — 6 ft lengths, 6 lin. ft
10. 1-1/4 in. top rail of chain-link fence, 26.5 lin. ft
11 1:1 toroid balun, 1 ea.
12. No. 6-32 X 1 in. stainless steel screws, 8 ea.
    No. 6-32 stainless steel nuts, 16 ea.
    No. 6 solder lugs, 8 ea.
13. No. 12 copper feed wire, 22 lin. ft
14 12 in. X 6 in. X 1/4 in. aluminum plate, 1 ea.
15. 6 in. X 4 in. X 1/4 in. aluminum plate, 1 ea.
16. 3/4 in. galv. pipe, 3 lin. ft
17. 1 in. galv. pipe — mast, 5 lin. ft
18. Galv. guy wire, 50 lin. ft
19. 1/4 in. X 2 in. turnbuckles, 4 ea.
20. 1/4 in. X 1-1/2 in. eye bolts, 2 ea.
21. TV guy clamps and eyebolts, 2 ea.

1 in. = 25.4 mm
1 ft = 0.30478 m

author's 14-MHZ Log-Yag on-the-air performance on cw and ssb substantiates the theory. The characteristics of the array are given in Table 3.

The materials needed are given in Table 5. In the construction diagram, Fig. 12, the materials are referenced by their respective material list number. The photographs show the overall construction picture, and the drawings show the details.

The materials should be available from most hardware and electronic stores. However, some have found difficulty in obtaining aluminum tubing. This can be solved by writing to the manufacturer and asking for the name of their distributor nearest your locality. Commercial antenna manufacturers will sell their tubing, but the cost is at a premium.

This array is in operation at K4EWG and W4BBP. The results on the air are nothing short of fantastic! It will give the stacked Yagis and long-boom Yagis a run for their money.

It is the authors' hope that this antenna design will stimulate additional work and research by other amateurs. The field seems wide open, and Yag-Log combinations are endless. The optimum design is by no means achieved in this article. It does seem, however, that a log cell of more than four elements would be necessary only where the array bandwidths, B, exceed 1.03 ($B = f_n/f_1$).

The authors wish to thank George Smith, W4AEO, for his work in substantiating a consideration for log periodic gain.[8] This material was originally presented in *QST* by P. D. Rhodes, K4EWG and J. R. Painter, W4BBP.

References

[1] "The Swan Multidrive 2-Meter Antenna," *QST,* Oct. 1969.

[2] Orr, *Radio Handbook,* 18th edition, pp. 547-548.

[3] Rhodes, "The Log-Periodic Dipole Array," *QST,* November 1973.

[4] *The ARRL Antenna Book,* 13th edition, p. 151.

[5] See ref. 2 above, p. 558.

[6] King, Mack and Sandler, "Arrays of Cylindrical Dipoles," *Yagi-Uda Programme Apdx. V,* 1968, pp. 218-232, 468-470.

[7] See ref. 4 above: pp. 160-164, 208-210, and Fig. 9-18.

[8] Smith, "Yes, I've Built Sixteen Log Periodic Antennas!" *73,* March 1975. See pp. 98-99.

[9] Orr, "Antennas," *CQ,* March 1975. See section headed "The KLM Antenna."

[10] See ref. 4 above, p. 204 and Fig. 9-5.

Chapter 3

Quad Antennas

A currently popular form of directional gain antenna is called the "quad." In general performance principles, it compares favorably to the Yagi beams discussed in chapter 2. The proper name for this antenna is the "cubical quad." It was developed by Clarence Moore, W9LZX, in 1942 when he was an engineer for HCJB in Quito, Ecuador. The design came as a solution to large corona discharges at the ends of existing beam-antenna elements. The problem was caused by the highly ionized air at the transmitter location, some two miles above sea level. Operation was in the commercial 25-meter band, which for the intentions of the broadcaster, required a gain type of antenna.

Moore concluded that a gain antenna with no ends was required to handle the 10-kW power without corona or flashover. Thus, the quad was born. Not only did it handle the power without difficulty, it later became a popular amateur antenna after he developed a model for use on 20 meters.

The primary limitation of quad antennas is the unwieldy nature of the "beast," especially at 40 and 20 meters, compared to a Yagi. The supporting framework is subject to extreme stress from ice and wind loading. Nonetheless, the quad has proven to be one of the most effective DX beams that an amateur can buiid at modest cost. This chapter contains data on various types of quads for a number of amateur bands. It is a compendium of the best on the subject, as published in past issues of *QST*.

Quads and Yagis: Comparisons, Patterns and Working Dimensions

Want a fresh look at the Yagi vs. quad question? This is "must" reading for the antenna-minded.

The material in the following sections will present a discussion of two time-tested antenna arrays.

In this class of arrays the Yagi (more properly the Yagi-Uda) antenna is the grandfather of them all. There are very few antennas which can compete with the electrical operation and simplicity of construction of this array. However, in the early 1940s C. C. Moore, of radio station HCJB, brought into being a parasitic array of loop elements with properties very comparable to those of the Yagi-Uda array. Since its conception this array has become very popular in Amateur Radio circles. It has come to be known as the "cubical quad" or "quad" antenna because of the common use of square loops and box-like construction.[1]

The material to follow will attempt to present an unbiased comparison of these two arrays based upon the experimental and theoretical results of many workers. This material is prefaced by a short section of introductory antenna concepts and definitions so that certain terms and notation will have more meaning when the comparisons between the quad and Yagi antennas are made. Finally, in the last section, some of the experimental patterns of modeled quad and Yagi arrays are presented. A compilation of some of the working dimensions for both types of arrays are also given. This latter material should be of interest to the builder and experimenter.

Introductory Antenna Theory and Definitions: Polarization

Inspection of the radiation field of an antenna will show it to have plane-wave character and to be made up of electric and magnetic field lines which are perpendicular to each other. Polarization of an electromagnetic wave is defined as that direction in which the electric field lines are oriented. If the electric field vector is fixed (in direction) in a plane it is said to be linearly polarized. For example, the polarization of a dipole is linear. If the plane in which this dipole lies is horizontal or parallel to some reference plane (e.g., the surface of the earth), it is called a horizontally polarized antenna. Vertical polarization would result if the dipole were placed perpendicular to the reference plane. It should be noted that if the electric vector does not stay fixed in position but rotates (its tip tracing out an ellipse), then the wave is said to be elliptically polarized. Circular polarization is a special case of elliptical polarization. Elliptical polarization will have a right- or left-hand sense, depending upon the direction of rotation of the electric vector.

Directivity and Gain of an Antenna

The degree to which a particular antenna can concentrate the antenna pattern into a beam is known as *directivity*. Mathematically, it is the ratio of the power density (in watts per square unit of measure) that would be available at an observation point to the power density one would have if the total radiated power were radiated *equally* well in *all* directions.[2] Directivity is a function of the antenna pattern alone and does not take into account antenna efficiency or losses.

The gain of an antenna can be defined in terms of directivity when antenna efficiency is taken into consideration. If K is the antenna efficiency, a number between 0 and 1, then antenna gain is given by

$$G = KD$$

where

G = antenna gain
K = antenna efficiency
D = directivity

The gain in decibels is then given by

$$\text{dB gain} = 10 \log_{10} G.$$

Please note that the above definition has been such that it is a function of the observation point. In amateur circles gain is usually measured at that observation point where the maximum power density is observed. Further, when considering practical Yagi and quad arrays for the hf range, K is normally taken as 1. Gain measured in the above manner is normally called gain with respect to an isotropic antenna. It is interesting to note that since a half-wave dipole concentrates its pattern into certain directions, it will have some gain with respect to an isotropic antenna. This gain with respect to isotropic is found to be

$$G = 1.64$$

or, in dB,

$$G_{dB} = 2.15 \text{ dB}$$

If the vertical and horizontal half-power beam widths are known for a given antenna the following formula will give (somewhat on the generous side) the gain of the antenna with respect to an isotropic antenna

$$G = \frac{40{,}000}{\theta_H \theta_V}$$

where

θ_H = horizontal half-power beam width in degrees.

θ_V = vertical half-power beam width in degrees.

This formula assumes low-side and back-lobe levels for the antenna pattern. If the gain with respect to isotropic is known then the gain with respect to a half-wave dipole is obtained by subtracting 2.15 dB.

Antenna Aperture or Area

This concept is of most use when discussing a receiving antenna. It is a measure of the antenna's ability to gather in available radiated power at some receiving position. Antenna area and gain are *directly* related

$$G = 4\pi \frac{A}{\lambda^2}$$

where

G = antenna gain

λ = operating wavelength

A = area (based upon square units of length measurement, with the length measurement the same as that assumed for λ). It should be noted that one *cannot* have two antennas with the same gain and different areas. One hears this concept misused (in the sense of the above sentence) quite often on the amateur bands. That is to say, if you feel that one antenna has more capture area than another, then it must also have more gain.

Antenna Patterns

The pattern of an antenna may be plotted by recording the received electric field strength or power density as a function of viewing (observation) angle. The properties of most antennas used by radio amateurs (below 30 MHz) can be described by two basic patterns. Consider a pattern due to a radiating half-wave dipole, this pattern to be obtained by moving a sampling or test antenna about the dipole in the horizontal plane which contains the dipole. This pattern is called the horizontal-plane or E-plane pattern (the pattern was taken in a plane containing the electric E-lines, hence the name E-plane pattern). If the sampling antenna is placed directly in front of the horizontal dipole (and in the horizontal plane) and moved up over the top of the dipole (in a plane perpendicular to the horizontal plane), and on around until it returns to the starting position, the result is the vertical-plane or H-plane pattern (since the test antenna moved in a plane parallel to the magnetic H-lines it is called an H-plane pattern).

For Yagi and quad arrays these two patterns will give enough essential information to determine their expected radiating properties.

Comparison of Quad and Yagi Arrays

The cubical quad antenna was first introduced to the radio world in 1942 by Clarence C. Moore at HCJB to alleviate a serious corona problem occurring on a large commercial shortwave Yagi array. It is a parasitic array formed with loop elements which are approximately one wavelength in circumference.

Important to proper operation of a quad antenna are considerations of proper element sizes, spacing between elements, boom length, feed impedance and so forth. The following material presents a discussion of these considerations and a comparison of the quad and Yagi arrays.

Polarization of a Quad Antenna

The polarization of a quad antenna can be determined by considering the current distribution on the driven element. To stress the point that square, diamond, or circular loop all produce essentially the same polarization, consider the current distribution shown in Fig. 1. A little thought reveals that fact that the vertical components of current produce radiated fields that cancel each other, and the horizontal components of current produce a radiated field (broadside to the loop) with all components adding. The polarization of any of these loops is then linear and parallel to an imaginary horizontal line drawn through the current minima. Hence, if a quad loop is fed at the bottom it produces horizontal polarization, and if fed on the side it will have vertical polarization. The geometrical form of the loop, square, diamond or circular, does not mean that the (broadside) radiation has a possible combination of both horizontal and vertical polarization or circular polarization. This seems to be a common misconception in amateur circles. The linear polarization properties introduced above can be verified easily experimentally. It should be further noted that there are no noticeable differences in the radiating properties or impedance of a loop 1 wavelength in circumference whether it be of the circle, diamond or square configuration.

Angle of Radiation for a Horizontally Polarized Quad Antenna

Placement of an antenna above a conducting ground will alter its free-space radiation pattern, positioning the maximum of its main lobe at possibly a new angle with respect to a horizontal reference line. The angular position of this main lobe is called the *angle of radiation*. The angle of radiation of an antenna is a function of its height above the conducting ground and its polarization. Given the height and the polarization, the angle of radiation can be determined by using the concept of the antenna's virtual image or ray theory and reflection of the wave by the ground.

The following conclusions can now be drawn:

The angle of radiation of a *horizontally* polarized quad antenna, at a given boom height, is essentially the *same* as that of a *horizontally* polarized Yagi at the same boom height.

This must be so because the boundary conditions imposed upon the electromag-

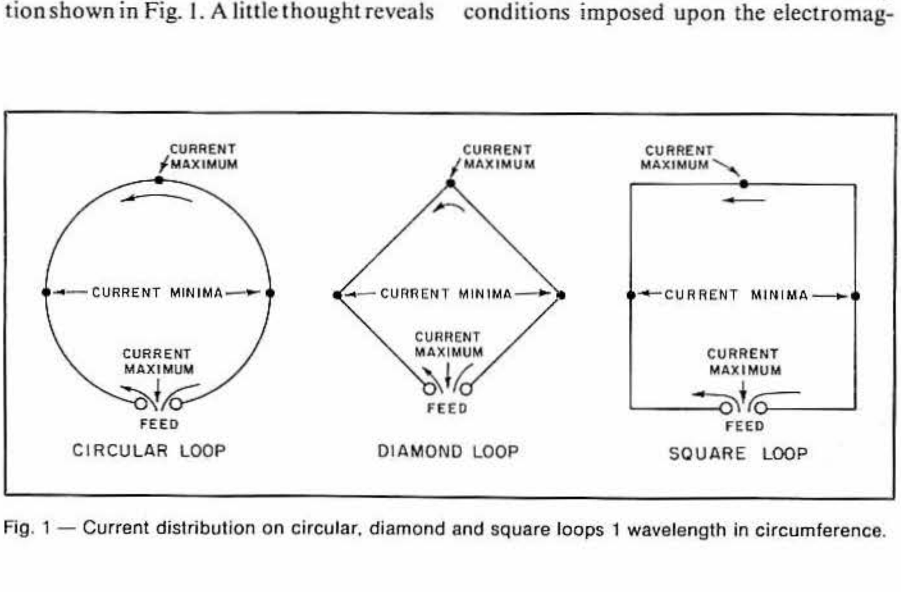


Fig. 1 — Current distribution on circular, diamond and square loops 1 wavelength in circumference.

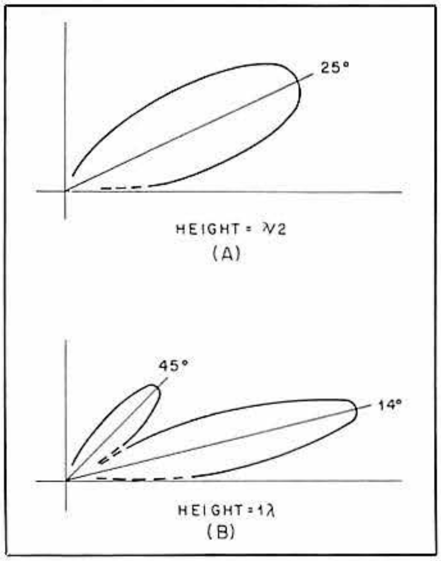


Fig. 2 — Vertical-plane radiation patterns for a horizontally polarized quad or Yagi array above perfectly conducting ground.

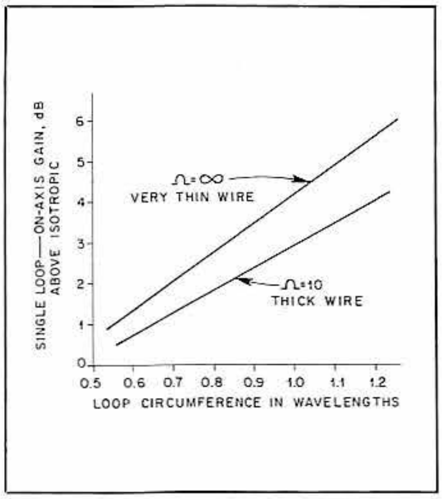


Fig. 3 — On-axis gain of a single loop as a function of loop circumference. (From "Studies of Large Circular Loop Antennas" by S. Adachi and Y. Mushiake *Sci. Rep. Ritu*, B-[Elect. Comm.] vol. 9, no. 2, Tohoku Univ., Sendai, Japan, 1957.)

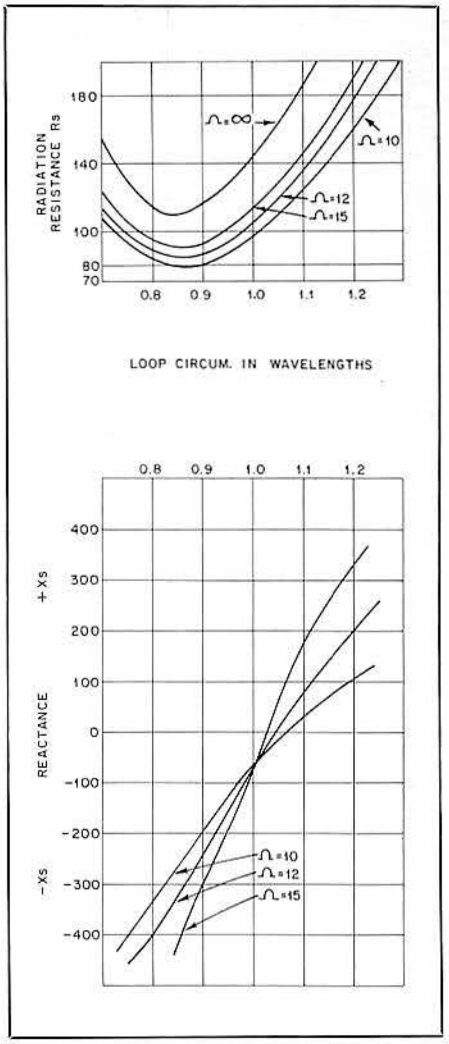


Fig. 4 — Reactance and radiation resistance of a single loop versus circumference. Note: Ω is a measure of the ratio of loop circumference to wire diameter. $\Omega = 2\ln 8a/\rho$ where a = loop radius and ρ = wire radius.

netic wave at the surface of ground are completely insensitive to the fact that the wave is produced by a quad antenna as opposed to the wave produced by a Yagi antenna.

Typical patterns of a quad *or* Yagi antenna placed at a height of 1/2 λ or 1 λ above a perfect ground are shown in Fig. 2 at A and B.

Gain Comparisons of the Quad Antenna with the Yagi Antenna

The gain of a quad array (of given boom length) seems to be somewhat higher than that of a Yagi array of the same boom length. This gain difference can be explained by considering the theoretical work of Adachi and Mushiake of Tohoku University in Japan. In 1952 and 1957 they published two papers which discussed the current distribution, impedance, and radiating properties of loops of large circumference.[3]

Fig. 3 shows the gain of a single loop as a function of wavelength and wire diameter. Fig. 4 shows the variation of reactance and radiation resistance for a single loop. Please note the dependence upon the circumference-to-wire-diameter ratio in these two figures. They showed that the broadside gain of a single loop 1λ in circumference was approximately 2 dB above that of a half-wave dipole. This result implies that a parasitic array of loop elements should have the same gain advantage when compared to a Yagi array of comparable boom length.

This gain differential for the quad array does appear and can be verified experimentally. Fig. 5 demonstrates this comparison. The points on the figure were obtained as follows: For the antenna under consideration E and H plane patterns were made. The gain was then calculated using the E and H-plane half-power beam widths of these radiation patterns and the formula discussed above. This gain and the boom length of the antenna were then used to determine a point on the graph given in Fig. 5, where gain and boom length represent the parameters under consideration. The data points for many, many antennas, both quad and Yagi, were then placed on the graph and a smooth curve representing an average for each type of antenna was then drawn.

The expected gain difference of 2 dB does indeed appear in favor of the quad antenna. This gain differential is essentially that predicted by the results of the Japanese workers cited above.

The measurements used to obtain the above gain comparisons were performed at 440 MHz. A measuring frequency of 440

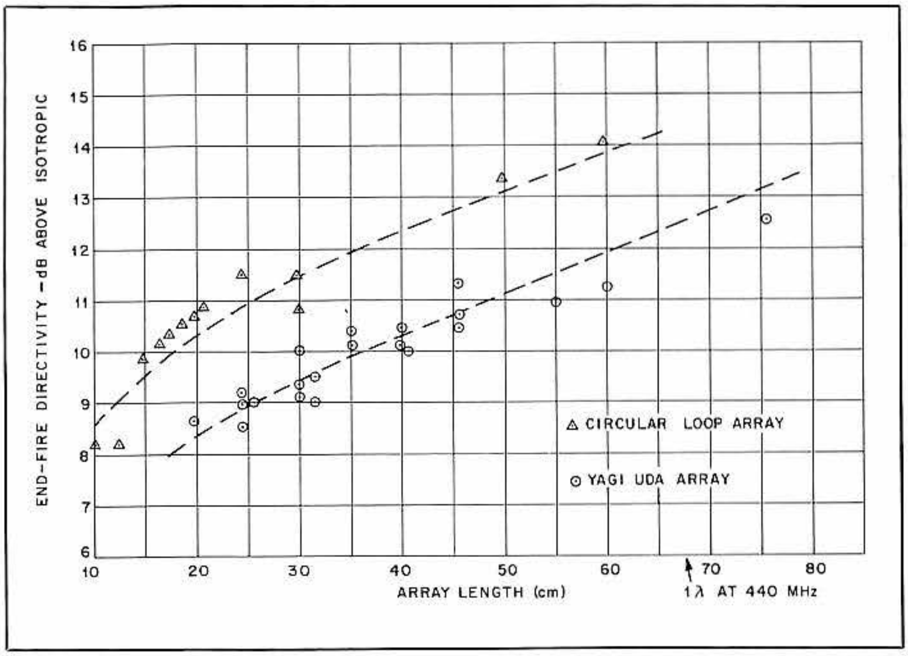


Fig. 5 — Quad and Yagi array gain as a function of boom length.

Table 1

Quad Dimensions

2-element Quad (W0HTH)
Spacing (given below)
Boom length (given below)

Band	*40 M*	*20 M*	*15 M*	*10 M*
Reflector	144 ft 11-1/2 in.	72 ft 4 in.	48 ft 8 in.	35 ft 7 in.
Driven Element	140 ft 11-1/2 in.	70 ft 2 in.	47 ft 4 in.	34 ft 7 in.
Spacing	30 ft	13 ft	10 ft	6 ft 6 in.
Boom length	30 ft	13 ft	10 ft	6 ft 6 in.
Feed method	Directly with 23 ft of RG-11, then any length RG-8 coax.	Directly with 11 ft 7 in. RG-11, then any length RG-8 coax.	Directly with 7 ft 8-1/2 in. RG-11, then any length RG-8 coax.	Directly with 5 ft 8 in. RG-11, then any length RG-8 coax.

(Note that a spider or boomless quad arrangement could be used for the 10/15/20 meter parts of the above dimensions yielding a triband antenna)

4-element Quad* (W0AIW [20 M] /W0HTH** /K0KKU/K0EZH/W6FXB)
Spacing: equal; 10 ft
Boom length: 30 ft

Band	*20 M*		*15 M*	*10 M*
	Phone	CW		
Reflector	72 ft 1-1/2 in.	72 ft 5 in.	48 ft 8 in.	35 ft 8-1/2 in.
Driven Element	70 ft 1-1/2 in.	70 ft 5 in.	47 ft 4 in.	34 ft 8-1/2 in.
Director 1	69 ft 1 in.	69 ft 1 in.	46 ft 4 in.	33 ft 7-1/4 in.
Director 2	69 ft 1 in.	69 ft 1 in.	46 ft 4 in.	33 ft 7-1/4 in.
Feed Method	Directly with 50-ohm coax.		Directly with 50-ohm coax.	Directly with 5 ft 9 in. RG-11, then any length RG-8 coax.

*Common boom used to form a triband array.
**The 2-element 40-meter quad given above is added to form a four-band quad array.

4-element Quad (W0HTH/K8DYZ*/K8YIB*/W7EPA*)
Spacing: equal; 13 ft 4 in.
Boom length: 40 ft

Band	*20 M*	*15 M*	*10 M*
Reflector	72 ft 5 in.	48 ft 4 in.	35 ft 8-1/2 in.
Driven Element	70 ft 5 in.	47 ft 0 in.	34 ft 8-1/2 in.*
Director 1	69 ft 1 in.	46 ft 1 in.	(Directors 1-3 all 33 ft 7 in.)*
Director 2	69 ft 1 in.	46 ft 1 in.	
Feed method	Directly with 50-ohm coax.	Directly with 7 ft 9 in. RG-11, then any length 50-ohm coax.	Directly with 50-ohm coax.

*For the 10-meter band the driven element is placed between the 20/15 reflector and 20/15 driven element. The 10-meter reflector is placed on the same frame as the 20/15-meter reflectors and the remaining 10-meter directors are placed on the remaining 20/15-meter frames. The 10-meter portion is then a 5-element quad.

6-element Quad (W0YDM, W7UMJ)
Spacing: equal; 12 ft
Boom length: 60 ft

Band: 20 M

Reflector	72 ft 1-1/2 in.
Driven Element	70 ft 1-1/2 in.
Directors 1, 2 and 3	69 ft 1 in.
Director 4	69 ft 4 in.
Feed Method	Directly with 50-ohm coax.

1 ft = 0.3048 m

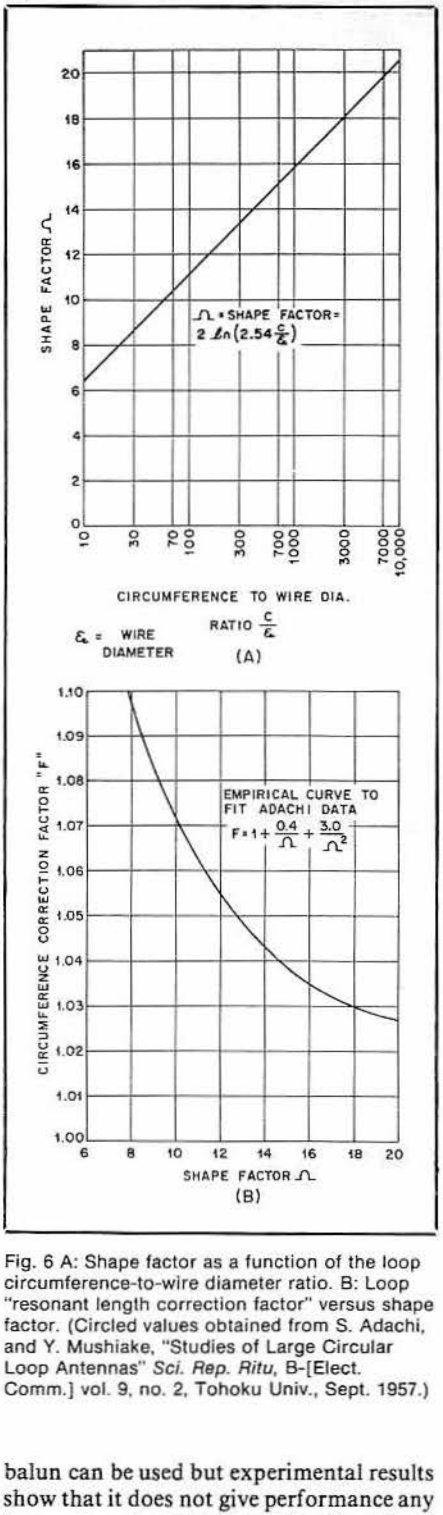


Fig. 6 A: Shape factor as a function of the loop circumference-to-wire diameter ratio. B: Loop "resonant length correction factor" versus shape factor. (Circled values obtained from S. Adachi, and Y. Mushiake, "Studies of Large Circular Loop Antennas" *Sci. Rep. Ritu*, B-[Elect. Comm.] vol. 9, no. 2, Tohoku Univ., Sept. 1957.)

MHz was chosen so that 1 cm (at this frequency) is equivalent to 1 foot of measurement at 14 MHz. Hence, to relate these results directly to the 20-meter amateur band, boom length in cm from the curve can be read as boom length in feet. For example, the gain of a quad on a 40-foot (12.19-m) boom should be slightly more than 1 dB above a quad on a 25-foot (7.62-m) boom. Comparison of the signals from these two antennas at a receiving station will not reveal much difference; however, in the DX pile-ups the longer antenna should have a slight advantage. Another interesting interpretation of these results is to note that a quad on a 30-foot (9.14-m) boom is equivalent to a Yagi on a 55-foot (16.76-m) boom. Hence the boom of a Yagi antenna must be about 1.8 times longer than the boom of a quad in order for the two gains to be comparable.

Impedance Properties and Matching

The driving-point impedance of a quad antenna depends upon the element spacing and number of elements. For 2-element quad antennas the results of Bill Orr in his *Quad Antenna* handbook can be used to determine the driving-point impedance. For multielement quads (3 or more elements)[4] the impedance will range from 40 to 60 ohms. Matching of these multielement quads is most easily done by direct feed with a 50-ohm coaxial line. A 1:1 balun can be used but experimental results show that it does not give performance any better than that obtained with direct feed. A gamma match can be used to obtain an exact match to any chosen coaxial line. For details of using a gamma match on a quad antenna see Bill Orr's *Quad Antenna* handbook.

If a single boom is used to construct a multiband quad antenna, then it is recommended that a separate feed line to each driven element be used.

Approximate Formulas for Quad Antenna Element Lengths

The multielement quad antenna gained its first real popularity following the work of Lee Bergren, W0AIW, in the early 1960s. He published the results of his work in *QST* in 1963.[5] Many experimentalists have used his dimensions for antennas in the 20-meter amateur band and have scaled them to other bands. Based upon Bergren's work and others the following empirical formulas can be used to determine the element lengths of a quad antenna

$$\text{Circumference of driven element} = \frac{1005}{f_{MHz}} \text{ feet}$$

$$\text{Circumference of reflector element} = \frac{1030}{f_{MHz}} \text{ feet}$$

$$\text{Circumference of director elements} = \frac{975}{f_{MHz}} \text{ feet}$$

These results should only be used for quad antennas operating below 30 MHz. It is interesting to note that for quad antennas the reflector and directors are only 2-1/2 to 3 percent different in length from the driven element. This is a smaller change than that normally encountered in Yagi arrays.

The above figures should not be used for vhf or uhf quad antennas. At these higher frequencies the circumference-to-wire-diameter ratio becomes small enough that its effect upon the resonant properties of the loop must be considered. Here again, the results of Adachi and Mushiake are useful and the effects of wire size on the resonant length of the loop can be taken into account. These results are given in graphical form in Fig. 6 where, based upon the circumference-to-wire-diameter ratio, a circumference correction factor can be obtained. Once the correct size of the driven element is determined (using the results of Fig. 6) a quad antenna can be designed by making the reflector approximately 3 percent longer and the directors 3 percent shorter.

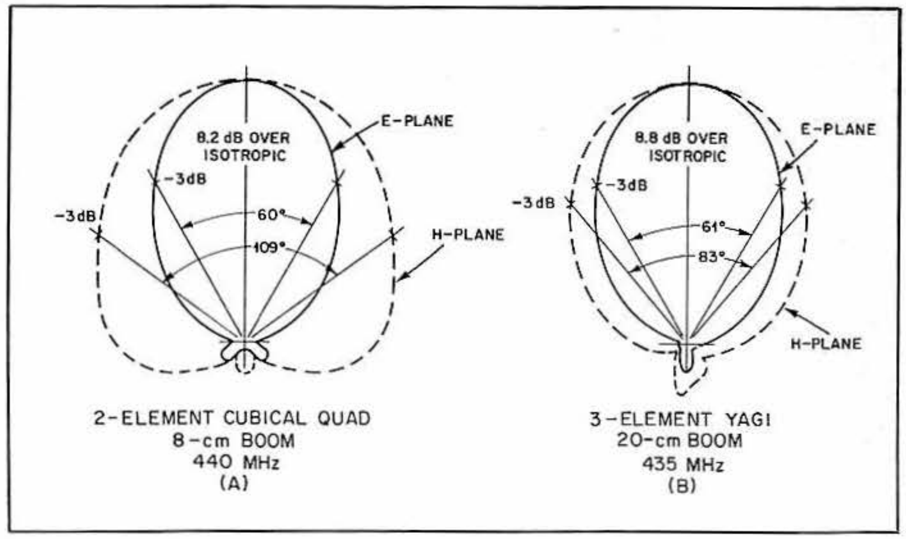
The above results can be used to obtain workable dimensions but, just as with approximate formulas for Yagi antenna element lengths, the "best" dimensions would have to be determined experimentally by tuning the array.

A Collection of Quad and Yagi Patterns and Dimensions: E and H Plane Patterns for Quad and Yagi Arrays

The previous section referred to a group of experimental tests, where a series of model antennas were constructed and the E and H plane patterns obtained.

It should be noted that these patterns have direct interpretation in light of the 20-meter band. Recall that the experiments were performed at 440 MHz, where dimensions for boom length, element size, and spacing in cm are directly equivalent to dimensions in feet for the 20-meter band. For example, the patterns for a 440-MHz, 5-element Yagi on a 55-cm boom can also be taken as the pattern for a 14-MHz, 5-element Yagi on a 55-foot boom.

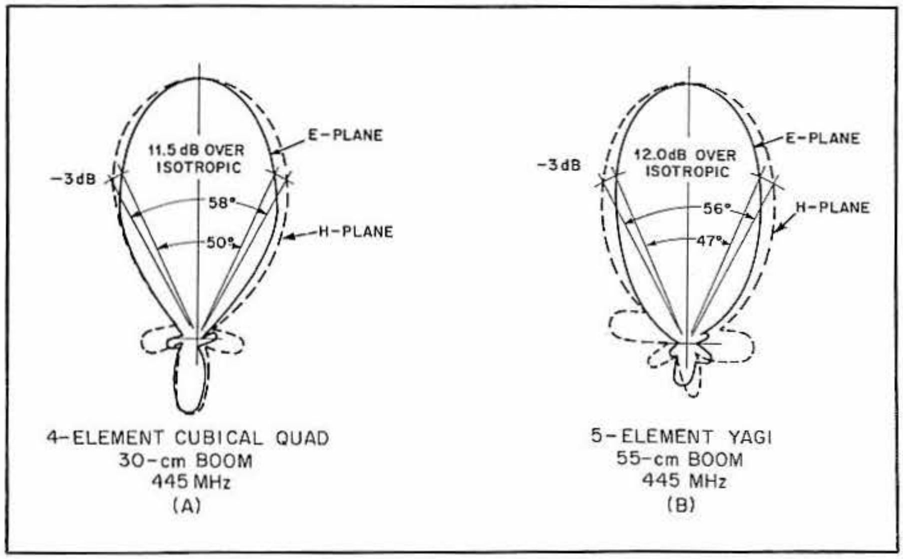
Perusal of these patterns will give a



2-ELEMENT CUBICAL QUAD
8-cm BOOM
440 MHz
(A)

3-ELEMENT YAGI
20-cm BOOM
435 MHz
(B)

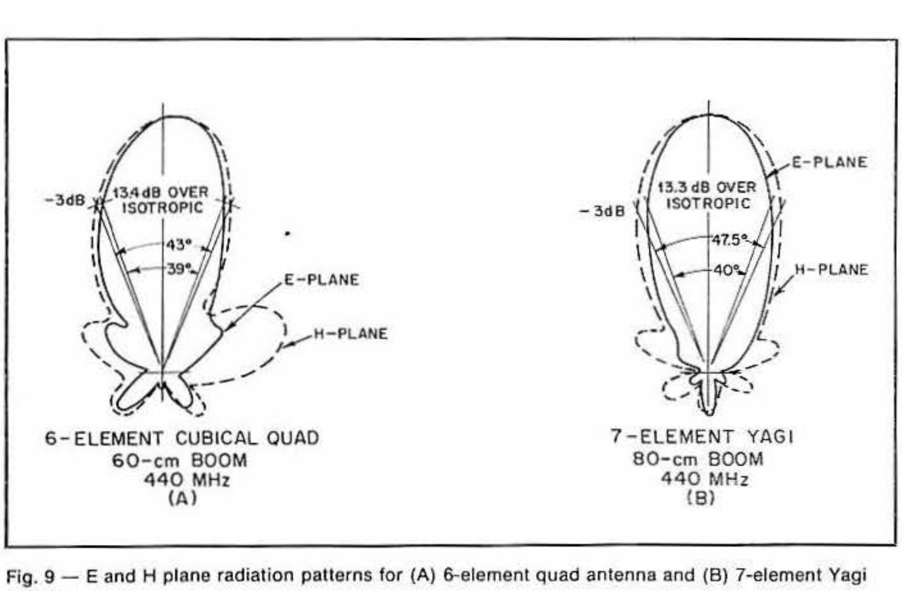
Fig. 7 — E and H plane radiation patterns for (A) 2-element quad antenna and (B) 3-element Yagi antenna.



4-ELEMENT CUBICAL QUAD
30-cm BOOM
445 MHz
(A)

5-ELEMENT YAGI
55-cm BOOM
445 MHz
(B)

Fig. 8 — E and H plane radiation patterns for (A) 4-element quad antenna and (B) 5-element Yagi antenna.



6-ELEMENT CUBICAL QUAD
60-cm BOOM
440 MHz
(A)

7-ELEMENT YAGI
80-cm BOOM
440 MHz
(B)

Fig. 9 — E and H plane radiation patterns for (A) 6-element quad antenna and (B) 7-element Yagi antenna.

visual means of comparing the quad and Yagi arrays. It is interesting to note the dependence of gain and pattern beam width upon array boom length. Without further comment, typical patterns for both types of antennas are given in Figs. 7 through 9.

A Tabulation of Dimensions of Working Arrays

Presented in tabular form are a few representative dimensions for both quad and Yagi antennas. These are dimensions presently in use by a number of amateurs. Most of the Yagi dimensions are due to amateurs across the country who sent their dimensions to Mr. Hal Wolff or the author to be modeled on the antenna range at the University of Denver. The quad dimensions also are those now in use by a number of amateurs in this country and abroad. It should be noted that most of these dimensions, and the resulting model antennas, provided the necessary data used in the previous section to compare the quad and Yagi. Where known, either the user(s) or the originator of a set of dimensions is indicated. The first set of dimensions is for quad antennas, the second set for Yagi antennas.

Table 2

Yagi Dimensions

3-element Yagi (W6SAF)
Boom length: 24 ft
Band: 20M

	Element Length	*Spacing*
Reflector	34 ft 10-3/4 in.	R—DE: 13 ft 9-1/2 in.
Driven Element	33 ft 2-1/2 in.	DE—D: 10 ft 4-1/2 in.
Director	31 ft. 9-1/2 in.	

3-element Yagi (W0OKC)
Boom length: 26 ft
Band: 20M

	Element Length	*Spacing*
Reflector	35 ft 6 in.	R—DE: 14 ft
Driven Element	33 ft 4 in.	DE—D: 12 ft
Director	31 ft 7 in.	

3-element Yagi (W0CM, formerly W0JYW)
Boom length: 30 ft
Band: 20M

	Element Length	*Spacing*
Reflector	35 ft 4-1/2 in.	R—DE: 13 ft
Driven Element	32 ft 2-1/2 in.	DE—D: 17 ft
Director	31 ft 10 in.	
Feed Method	Folded dipole	

4-element Yagi (K0KKU)
Boom length: 30 ft
Band: 20M

	Element Length	*Spacing*
Reflector	35 ft 6 in.	(all elements equally spaced)
Driven Element	33 ft 4 in.	
Director 1	31 ft 9-1/2 in.	
Director 2	31 ft 2 in.	

4-element Yagi (W4PLL)
Boom length: 30 ft
Band: 20M

	Element Length	*Spacing*
Reflector	35 ft 4-1/2 in.	(all elements equally spaced)
Driven Element	33 ft 4-1/2 in.	
Director 1	31 ft 9-1/2 in.	
Director 2	31 ft 9-1/2 in.	

4-element Yagi (K6VIZ)
Boom length: 32 ft
Band: 20M

	Element Length	*Spacing*
Reflector	35 ft 6 in.	R—DE: 10 ft
Driven Element	32 ft 8 in.	DE—D1: 10 ft
Director 1	31 ft 8 in.	D1—D2: 12 ft
Director 2	31 ft 1 in.	

4-element Yagi (W0OKC)
Boom length: 36 ft
Band: 20M

	Element Length	*Spacing*
Reflector	35 ft 6 in.	R—DE: 14 ft
Driven Element	33 ft 4 in.	DE—D1: 10 ft 8 in.
Director 1	31 ft 8-1/2 in.	D1—D2: 11 ft 4 in.
Director 2	31 ft 1 in.	

4-element Yagi
Boom length: 40 ft
Band: 20M

	Element Length	*Spacing*
Reflector	35 ft 6 in.	R—DE: 14 ft
Driven Element	33 ft 4 in.	DE—D1: 12 ft
Director 1	31 ft 7 in.	D1—D2: 14 ft
Director 2	31 ft 0 in.	

5-element Yagi (WA6ZZK)
Boom length: 40 ft
Band: 20M

	Element Length	*Spacing*
Reflector	34 ft 10 in.	R—DE: 10 ft
Driven Element	33 ft 4 in.	DE—D1: 9 ft
Director 1	32 ft 6 in.	D1—D2: 10 ft 6 in.
Director 2	32 ft 2 in.	D2—D3: 10 ft 6 in.
Director 3	31 ft 10 in.	

5-element Yagi
Boom length: 46 ft
Band: 20M

	Element Length	*Spacing*
Reflector	35 ft 7-3/4 in.	
Driven Element	34 ft 5-3/8 in.	(All elements equally spaced at 11 ft 6 in.)
Director 1	33 ft 2 in.	
Director 2	31 ft 9-1/2 in.	
Director 3	30 ft 4-1/2 in.	

1 ft = 0.3048 m

Summary

A comparison between the quad and Yagi antennas, on the basis of gain, has been given, this comparison being based upon both theoretical and experimental results. The results indicate that if both antennas have the same boom length the gain of the quad array will be about 2 dB higher than that of the Yagi. For either antenna, gain is a function of boom length and will increase approximately 2.5 dB each time the boom length is doubled. Hence, a 2-dB gain advantage is equivalent to a boom-length advantage of 1.8. In other words, for the quad and Yagi arrays to have comparable gain, the boom length of the Yagi antenna must be 1.8 times longer than that of the quad.

The size of the wire used for the loop element (relative to the loop circumference) will have an influence upon the resonance and radiating properties of the loop. The influence of this shape factor — i.e., the ratio of loop circumference to wire diameter — can be accounted for by using the referenced results of Adache and Mushiake.

In conclusion, it might be stated that one type of antenna (quad or Yagi) is not necessarily better than the other. The choice between a quad or Yagi array will depend critically upon many factors. For example, if single-band operation is of main importance and the geographical area where the antenna is to be used does not have high-wind problems, the best and simplest choice would be a long-boom Yagi antenna. If multiband operation is desired, or if wind problems were to limit the length of the boom to some nominal value, then the quad antenna would be a good choice. Likewise, the choice of available materials in your locale, and the acceptance of the appearance of the antenna by your neighbors or family, constitute other determining factors. The best approach is to survey your requirements and

5-element Yagi (K6EVR)
Boom length: 46 ft
Band: 20M

	Element Length	*Spacing*
Reflector	35ft 4in.	R—DE: 12ft
Driven Element	33ft 5in.	DE—D1: 10ft
Director 1	31ft 8in.	D1—D1: 12ft
Director 2	31ft 8in.	D2—D3: 12ft
Director 3	31ft 8in.	

5-element Yagi (W8PWH)
Boom length: 52 ft
Band: 20M

	Element Length	*Spacing*
Reflector	35ft 11in.	R—DE: 13ft 10in.
Driven Element	33ft 4-1/2in.	DE—D1: 10ft 5in.
Director 1	32ft 10in.	D1—D2: 13ft 10in.
Director 2	31ft 2in.	D2—D3: 13ft 10in.
Director 3	30ft 9in.	

5-element Yagi (W4EX, formerly W4DQH)
Boom length: 54 ft
Band: 20M

	Element Length	*Spacing*
Reflector	35ft 0in.	R—DE: 13ft 6in.
Driven Element	33ft 4in.	DE—D1: 11ft 6in.
Director 1	32ft 3in.	D1—D2: 13ft
Director 2	32ft 1in.	D2—D3: 16ft
Director 3	31ft 11in.	

5-element Yagi (W6RR, formerly W6ITA)
Boom length: 55 ft
Band: 20M

	Element Length	*Spacing*
Reflector	34ft 9in.	R—DE: 16ft 9in.
Driven Element	33ft 7in.	
Director 1	31ft 11in.	(All elements equally spaced)
Director 2	31ft 9-1/2in.	
Director 3	31ft 8in.	

6-element Yagi
Boom length: 46 ft
Band: 20M

	Element Length	*Spacing*
Reflector	35ft 5in.	
Driven Element	34ft 5-1/2in.	(All elements equally spaced at 9ft 2-3/8in.)
Director 1	32ft 7in.	
Director 2	32ft 3in.	
Director 3	31ft 4-1/2in.	
Director 4	31ft 1/2in.	

6-element Yagi (W0OKC)
Boom length: 46 ft
Band: 20M

	Element Length	*Spacing*
Reflector	35ft 4in.	R—DE: 10ft
Driven Element	33ft 4in.	DE—D1: 8ft
Director 1	31ft 11in.	D1—D2: 9ft
Director 2	31ft 3-1/2in.	D2—D3: 9ft 6in.
Director 3	31ft 1/2in.	D3—D4: 9ft 6in.
Director 4	30ft 11in.	

6-element Yagi (W0OKC)
Boom length: 74 ft
Band: 20M

	Element Length	*Spacing*
Reflector	35ft 5in.	R—DE: 16ft 6in.
Driven Element	33ft 4in.	DE—D1: 9ft 9in.
Director 1	31ft 9-1/2in.	D1—D2: 14ft
Director 2	31ft 2-1/2in.	D2—D3: 17ft 6in.
Director 3	30ft 11in.	D3—D4: 21ft
Director 4	30ft 8in.	

7-element Yagi (W6HAW)
Boom length: 80 ft
Band: 20M

	Element Length	*Spacing*
Reflector	35ft 5in.	R—DE: 14ft
Driven Element	33ft 4in.	DE—D1: 11ft
Director 1	31ft 8in.	D1—D2: 12ft
Director 2	31ft 4in.	D2—D3: 13ft
Director 3	30ft 8in.	D3—D4: 14ft
Director 4	30ft 8in.	D4—D5: 16ft
Director 5	30ft 8in.	

8-element Yagi (WA6EKD)
Boom length: 100 ft
Band: 20M

	Element Length	*Spacing*
Reflector	34ft 9in.	(All elements equally spaced at 14ft 4in.)
Driven Element	33ft 5in.	
Director 1	32ft 2in.	
Director 2	31ft 11-3/4in.	
Director 3	31ft 9-7/8in.	
Director 4	31ft 8in.	
Director 5	31ft 2in.	
Director 6	30ft 11-3/4in.	

environmental restrictions, make your choice and proceed accordingly.

Acknowledgements

It is very difficult to acknowledge systematically and completely all those who have made the quad antenna a successful communications antenna. However, surely credit must be given to C. C. Moore, the father of the quad antenna, to William Orr, who presented the first written material on the theory and construction of 2-element quads; to Lee Bergren, who showed the feasibility and advantages of using multielement quad arrays; to the Japanese workers, Adache and Mushiake, of Tohoku University, who presented a detailed analysis and experimental verification of the electromagnetic properties of loop antennas of large circumference; and finally, to all the radio amateurs, in all corners of the world, who developed constructional and design techniques and proved or disproved their validity.

The author would like also to acknowledge the help of Mr. Hal Wolff (WA0IOR) for his aid in constructing the model Yagi and quad arrays and running the patterns. These patterns were obtained by using the antenna range of the Denver Research Institute of the University of Denver.[6] Many Denver-area amateurs have entered into these quad experiments, notably Messrs. Jim Snyder (K0ZCM), Butch Ford (WA0IMX), Ed Wood (K0KKU), Keith Farris (W0YDM), Warren Wheeler (W0R-EQ) and many others. The author gratefully acknowledges their assistance, help and encouragement. This material originally presented in *QST* by J. E. Lindsay, Jr., W7ZQ.

References

[1] For a colorful description of C. C. Moore's invention of the cubical quad antenna see the introduction of W. I. Orr's *Quad Antennas*, Radio Publications, Inc.

[2] An antenna which radiates equally well in all directions is called an isotropic radiator or isotropic antenna.

[3] Adachi and Mushiake, "Theoretical formulation for large circular loop antennas by integral equation method," *Repts. of the Research Institute of Elec. Commun.*, Tohoku University, Sendai, Japan, Sci. Rept. Ritu, B(Elec. Commun.), vol. 9, no. 1, 1957.

Idem., "Studies of large circular loop antennas," *Repts. of the Research Institute of Elec. Commun.*, Tohoku University, Sci. Rept. Ritu, B(Elec. Commun.), vol. 9, September 1952.

[4] Element spacing of 0.14λ to 0.2λ being considered.

[5] Bergren, "Multielement Quads," *QST*, May 1963.

[6] At the time these tests were performed (1962-64), the author was head of the Antenna Laboratory, Denver Research Institute, University of Denver. Mr. Hal Wolff was the research technician at this facility.

Additional References

Jasik, *Antenna Engineering Handbook*. New York: McGraw-Hill, 1961, pp. 16-25.

Lindsay, "A circular loop antenna with non-uniform current distribution," *IRE Trans. Antennas and Propagation (Communications)*, vol. AP-8, pp. 439-441, July 1960.

Lindsay, "A parasitic end-fire array of circular loop elements," *IEEE Trans. Antennas and Propagation (Communications)*, vol. AP-15, No. 5, pp. 697-698, Sept. 1967.

A Triband One-Loop Cubical Quad Element

Why not trade gain for economy and structural reliability? This three-band "DX Getter" consists of a single quad loop. It will stay aloft in high winds and won't look like an ugly monster to those who dwell nearby.

The advantages of a rotatable beam antenna are well known to all DXers. A problem arises in many situations regarding just how a reasonable compromise between antenna performance and cost, size and weight can be obtained. Because this author likes to live in peace with the XYL, the neighbors and the local council, the antenna must not be considered dangerous or an eyesore as far as appearance is concerned. In addition, the antenna must not hang over the fence of the 50- × 150-foot (15- × 46-m) block, half of which is already occupied by buildings. With these limitations firmly implanted in mind, the author added such factors as cost and difficulty of erecting and supporting a full-size, 20-meter Yagi or cubical quad. After weighing all the facts, it was felt that the only way out was to construct an economy-style, reduced-size antenna.

A single-loop, cubical-quad triband element is shown in Fig. 10. Such a cubical quad has only one-fourth the weight and wind resistance of a full-sized, three-element cubical quad of the same mechanical strength. The mechanical and installation difficulties are many times smaller; the cost of mast and rotor are also considerably reduced. Yes, the antenna is a compromise and the gain is less than that of a 3-element quad, but this antenna still puts a signal in good DX company. This quad, because of its smaller physical size, will be tolerated in many more locations than its big brother. If desired, this quad could be used as an indoor antenna strung between two opposite room walls.

Rather than going to a complicated switching arrangement to change bands, it was decided to apply what the author called the "triband-antenna principle" to this antenna. The theory behind this principle evolves around the same general ideas outlined by Pichitino in *QST*[1] several years ago. Antennas constructed along these guidelines do not operate harmonically and have only the desired resonances. The quad that was built is shortened only at the lowest operating frequency. It is full size at the middle operating frequency and much longer at the highest operating frequency. In addition, no heavy blocking tuned circuits are used near the element ends.

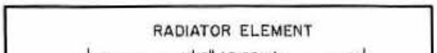


Fig. 10 — Single-loop triband cubical-quad element. Metric dimensions are shown; approximate English-unit dimensions are given in parentheses. Frequencies shown for C1L1 and C2L2 are those to which these circuits are tuned when disconnected from the loop.

C1 — 55 pF.

C2 — 49 pF.

L1 — 7 turns, No. 12, 38-mm (1-1/2-inch) diameter, space wound to 16 mm (5/8-inch) length.

L2 — 4 turns, No. 12, 38-mm (1-1/2-inch) diameter, space wound to 18 mm (11/16-inch) length.

L3 — 4 turns, No. 12, 38-mm (1-1/2-inch) diameter, space wound to 10-mm (3/8-inch) length.

With C1 giving 20-meter resonance depends mainly on the total element length and L1. Fifteen-meter resonance is controlled principally by C1 and L2. Ten-meter resonance is determined by C2 and L2. Once the antenna is constructed, it may be fine-tuned on each band by varying the constants that control the resonant frequencies. After the quad was tuned up, the author found the SWR on each band to be very satisfactory. On 20 meters, the antenna resonated at 14.15 MHz with a resulting SWR of approximately 1:1. With a 15-meter resonance at 21.3 MHz, an SWR of 1.3:1 was measured. On 10 meters, 28.6 MHz was selected as the resonant frequency. The resulting SWR at resonance on this band was 1.5:1. The phase relationship of the fields in L1 and L2 varies from band to band so that too much direct coupling between these coils should be avoided.

Although the author used copper wire to make the loop element, you may desire to use aluminum tubing. The actual constructional details are left to the builder. The materials used and the methods of supporting the antenna are limited only by your imagination. The techniques employed may be as simple or as sophisticated as you may desire. DJ2UT used short pieces of coaxial cable as capacitors and placed them inside the tubing which he used for the element. The coils and inner capacitor ends were sealed and molded in resin. Fifteen- and 10-meter resonances are obtained by shifting copper rings over the ends of L1 and L2. This can be done without affecting the sealed coils in any way.

The author concluded this antenna to be rather efficient based on observations that the tuning network does not become warm and a low SWR has been measured across each of the three bands. This writer wishes to thank OM Sommer, DJ2UT, and his co-workers for the very considerable amount of work carried out, and the many practical ideas which have made successful antennas with the triband principle possible. This material was originally presented in *QST* by Hans F. Ruckert, VK2AOU.

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[1] Pichitino, "A New Principle in Two-Band Rotary-Beam Design," *QST*, October 1948.

A 2-Element, 15-Meter Quad for the Novice

Why not build this 2-element quad for 15 meters? It is easy to construct, inexpensive and in many ways quite novel.

Not being blessed with a large area for antennas, the author decided on an optimum-spaced, 2-element monoband quad. The standard formulas were used for sides and spacing, and the antenna is fed with 50-ohm cable through a quarter-wave "Q" section of 75-ohm coax cut to the standard formula. The reflector has a tuning stub.

The driven element grid-dips at 21,150 kHz and the reflector was tuned by using the grid-dip oscillator as a signal generator. The grid-dip meter was placed in a neighbor's home. Then, the back of the quad was aimed at the dip meter, and the reflector was tuned for the lowest indication on the S-meter.

One of the checks made on the antenna was with VE5XH, in Swift Current, SK. Doug gave the following information: The quad has 2 S-units gain over my 1/4-wave groundplane which was at the same height. Strength off the front was S9 and to the rear was S2, indicating a good front-to-back ratio. Because the constructional details are rather novel, the author felt that other hams might be interested in how this antenna was built.

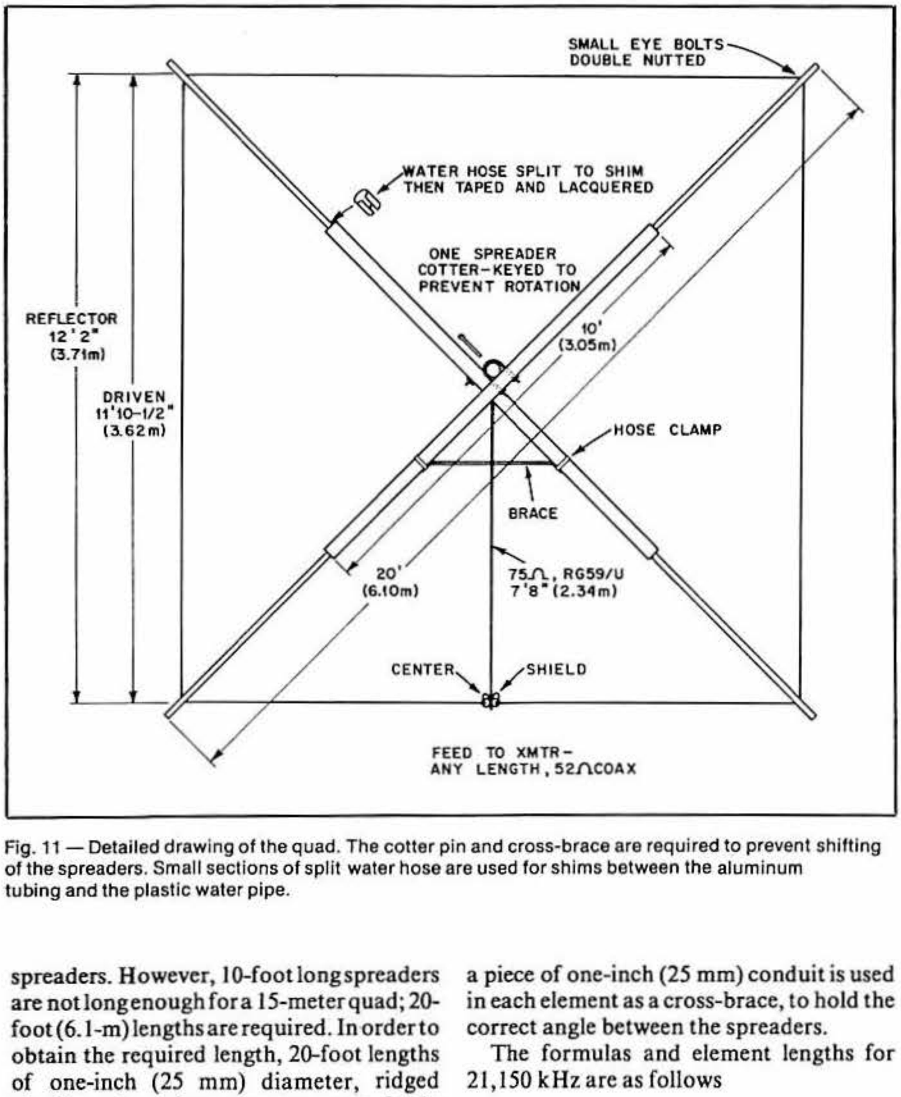
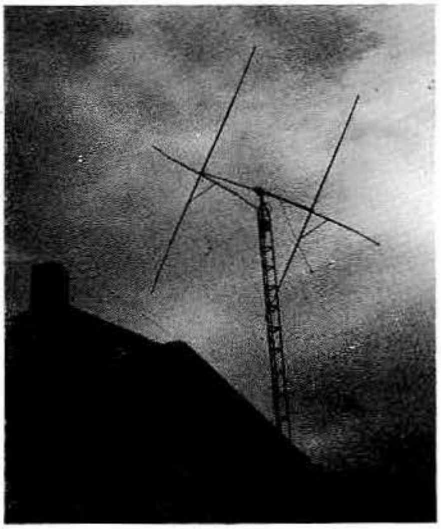

SMALL EYE BOLTS DOUBLE NUTTED
WATER HOSE SPLIT TO SHIM THEN TAPED AND LACQUERED
ONE SPREADER COTTER-KEYED TO PREVENT ROTATION
REFLECTOR 12'2" (3.71m)
DRIVEN 11'10-1/2" (3.62m)
10' (3.05m)
HOSE CLAMP
BRACE
20' (6.10m)
75Ω, RG59/U 7'8" (2.34m)
CENTER
SHIELD
FEED TO XMTR - ANY LENGTH, 52ΩCOAX

Fig. 11 — Detailed drawing of the quad. The cotter pin and cross-brace are required to prevent shifting of the spreaders. Small sections of split water hose are used for shims between the aluminum tubing and the plastic water pipe.

Construction

The author used 1-1/4-inch (32-mm) TV steel mast pipe, 10 feet (3 m) long, for the boom. Also, 10-foot lengths of TV mast sections, but aluminum, are used for the spreaders. However, 10-foot long spreaders are not long enough for a 15-meter quad; 20-foot (6.1-m) lengths are required. In order to obtain the required length, 20-foot lengths of one-inch (25 mm) diameter, ridged plastic water pipe were run completely through the 10-foot aluminum pipe sections. Pieces of rubber hose were used as shims between the aluminum pipe and the plastic pipe and these were taped where the plastic pipe emerges from the aluminum.



The completed quad on the tower. For tune-up, the quad was temporarily mounted on the garage roof.

The plastic water pipe comes in 20-foot lengths, 80 feet (24.4 m) being required. This pipe was purchased from a local plumbing and lighting outlet; the cost was $10 for the 80 feet. It is ridged plastic, but is not strong enough to support itself; so the aluminum mast pipe is used for the center portion of the spreaders.

The spreaders are clamped to the boom with standard U bolts, and one spreader in each element is pinned to the boom with a 5/16-inch (8 mm) cotter key. Additionally, a piece of one-inch (25 mm) conduit is used in each element as a cross-brace, to hold the correct angle between the spreaders.

The formulas and element lengths for 21,150 kHz are as follows

Driven element

$$\frac{1005}{f\,(\mathrm{MHz})} = 47\text{ feet, 6 inches (14.48 m)}$$

Reflector

$$\frac{1030}{f\,(\mathrm{MHz})} = 48\text{ feet, 8 inches (14.83 m)}$$

Boom spacing

$$0.2\text{ wavelength} = 0.2 \times \frac{984}{f\,(\mathrm{MHz})} = 9\text{ feet, 3 inches (2.84 m)}$$

75-ohm matching section

$$\frac{246 \times V}{f\,(\mathrm{MHz})} = \frac{162.4}{f\,(\mathrm{MHz})} = 7\text{ feet, 8 inches (2.34 m)}$$

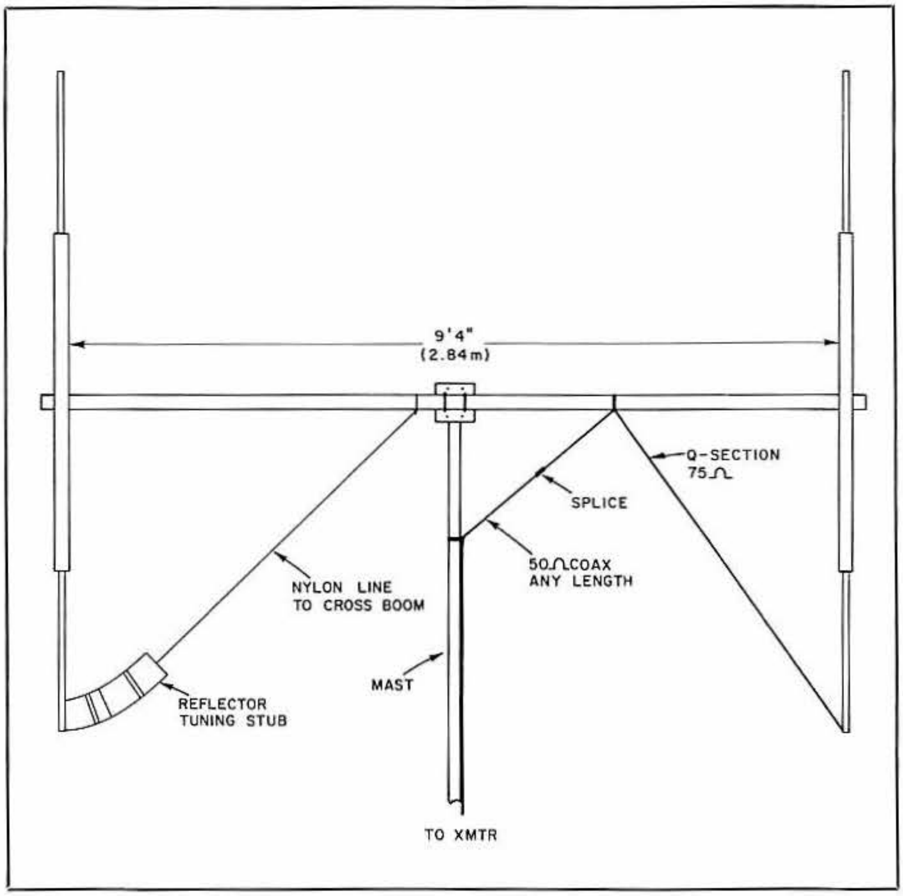


Fig. 12 — Side view, showing the mounting plate, Q matching section, and coax feed.

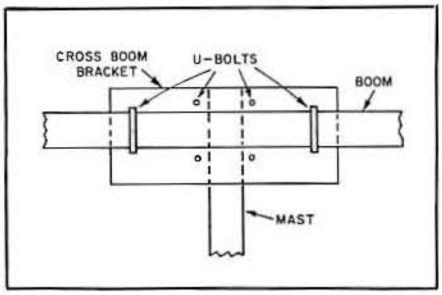


Fig. 13 — The cross-boom bracket, made from 3/8-inch (10 mm) aluminum plate. Ordinary TV U bolts are used to secure it to the boom and mast.

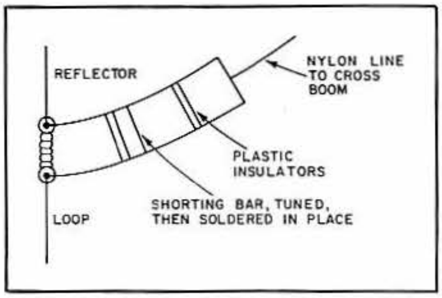


Fig. 14 — The reflector tuning stub is 36 inches (0.91 m) long. The shorting bar, a short piece of wire the same size as used in the stub was approximately 10 inches (254 mm) from the insulator when adjusted for maximum front-to-back ratio. Spacing between wires of the stub may be of the order of a few inches; this spacing is not critical since the stub length is adjusted by the shorting stub in the tune-up procedure.

The author used no. 14 soft-drawn enameled wire for loops and they were secured to the plastic pipe with double-nutted eye bolts. The reflector tuning stub was made from no. 12 copperweld wire. The total length of my stub is 36 inches (0.91 m), and after tuning, the shorting bar ended up approximately 10 inches (254 mm) from the loop.

The SWR showed almost a perfect match across the entire band. Since the quad was put up, the author has worked all continents and 35 countries on the Novice band. Stateside contacts always run S8 to S9. The total cost of the antenna was $28 at the time the system was built. This material was originally presented in *QST* by John Daebelliehn, WA9BJC.

A Practical 40-Meter Quad

One of the most perplexing problems continuously plaguing Field Day committees is how to install a good antenna system. For most clubs, finding a good location is generally the easiest job. The location must then be surveyed by the club antenna specialists. Deciding how many transmitters to use depends mostly on how many indivudual antennas can be set up for simultaneous operation as well as how many operators are available for the 24-hour stretch. Of course, an abundance of equipment is desirable.

Propagation conditions for Field Day and Sweepstakes generally favor the lower bands since they usually remain open all night. Success on the higher frequency bands (10 and 15 meters) depends primarily on catching the short-duration openings. The old trick of tying a rock to the end of a long piece of wire, tossing it into the tallest tree and loading it with a coupler just won't "cut the mustard" anymore. Gain and directivity into the dense population areas is the goal. However, the antenna must be simple to construct, easy to tune, and moderately stable against the wrath of Murphy and Mother Nature.

Our club decided to try a 2-element full-sized cubical quad for 40 meters. The immediate reaction within the more conservative ranks of our club was, "A 40-meter quad? It'll never work — the first breeze will knock it down!" With these objections in mind, we went ahead with our plans. Our location was approximately rectangular in shape, 60 feet wide, 500 feet long (18 × 152 m) and above the rest of the terrain. Of course, it just happened to be one of the highest locations in Winnebago County, IL!

The sketch illustrates the basic construction of the quad. Dimensions were estimated using the formula

$$L(\text{feet}) = \frac{248}{f(\text{MHz})}$$

where L is the length of one side of the diamond.

The parasitic element was constructed as a reflector using an extra long stub. A small relay shorts out the stub, thus converting the parasitic element from a reflector to a director (see Fig. 15).

The resonant frequency of the driven element is 7150 kHz, the middle of the band. The distance L for the driven element is 34 feet 8 inches (10.57 m). The parasitic element dimension is 5 percent smaller than the driven element. The stub is constructed so that the total circumference of the parasitic element with stub in the line is 5 percent greater than the driven element. L for the

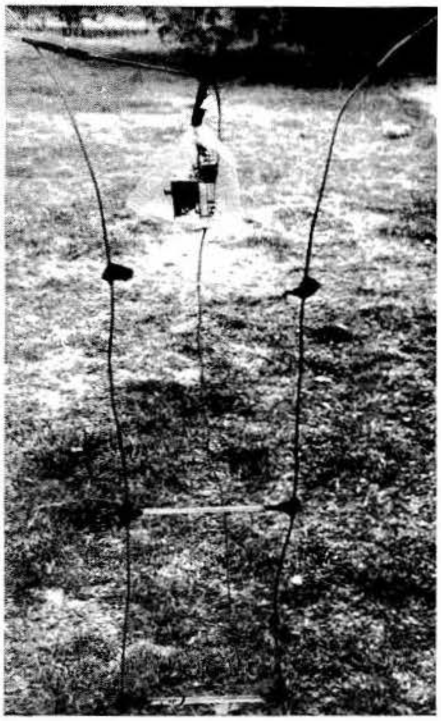


Fig. 15 — A simple relay arrangement is used to short out the stub and change the pattern of the antenna from one direction to another. A small plastic bag provides weatherproofing in the event it rains. (Doesn't it always?)

director is 33 feet (10.06 m). The stub length is 6 feet 9 inches (2.06 m). Eight-inch (203-mm) plastic spacers are placed between the two wires of the stub.

Supporting the quad is very simple. The mast is 50 feet (15.24 m) high, and guyed with nylon ropes. The boom is constructed from two telescoping sections of electrical conduit and is 18 feet (5.49 m) long. The elements are made from no. 14 stranded wire. The driven element is fed directly with RG-58/U coaxial cable. Location of the stub short is determined by the point of maximum front-to-back ratio. The boom-to-mast construction utilizes the support base from a Ham-M rotator. All it takes is a couple of U bolts and the boom-to-mast assembly is complete (see Fig. 16). The wire is strung from the end of the boom and is supported by a small piece of nylon rope and an egg insulator.

Results

Orientation for the quad was east and west. Favoring the eastern direction was the driven element/reflector combination, whereas the driven element/director combination was broadside to the western direction. A local amateur, approximately 5 miles (8 km) west of the Field Day site, assisted in tuning the quad for maximum front-to-back ratio. The end result was approximately 25 dB.

Results were a tremendous surprise! The antenna worked just as planned. The class of entry for simultaneous operation of two transmitters was used. One transmitter operated on 20 and 80 meters; the second transmitter was set up for 15 and 40 meters. Our club, W9AXD/9, scored third place in the two-transmitter class. Our biggest totals came from 40 meters — 693 contacts, over one third of our total number. For the first four hours of the contest, the antenna was aimed east. A rate of 90 contacts per hour prevailed for five solid hours. From that point on it was a steady decline after a sharp drop to about 45 contacts per hour. It was later surmised that the reason for the drop in contact rate was lack of activity and difficulty in finding stations that hadn't been worked before. The East Coast QRM was drastically reduced by changing the switch from "east" to "west." By midmorning we were surprised to find only a dozen W5 stations listed in the log. The antenna may not have been too effective in the southern direction.

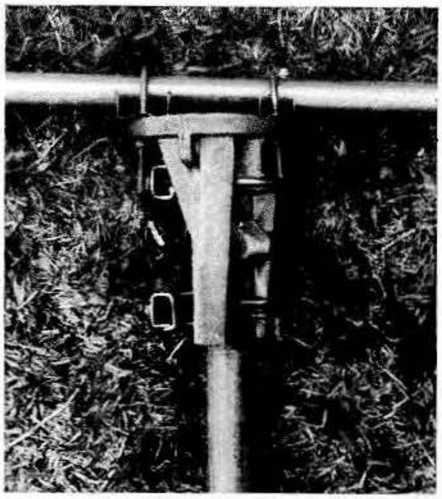


Fig. 16 — The bottom section of a CDE Ham-M rotor can be adapted to serve as a boom-to-mast bracket.

There is no reason why this arrangement could not be used for DX operating. The antenna could be positioned just underneath a beam for the higher frequency bands with the peak of the diamond supported from a boom placed through the top section of the tower.

This material was originally presented in *QST* by Peter H. Grillo, W6RTT.

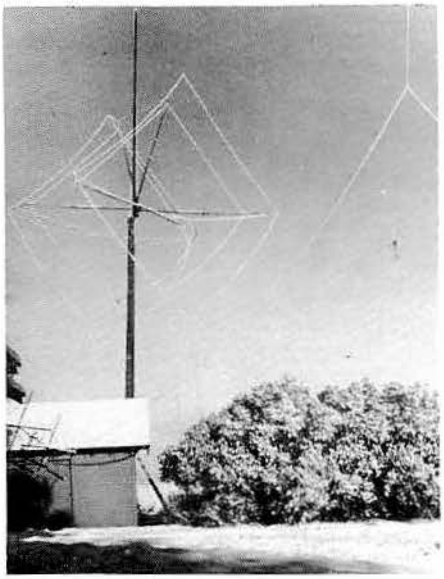
Build This C-T Quad Beam for Reduced Size

This quad-beam antenna, while smaller in size than a conventional quad, performs like a veteran. The trade secret is to use capacitive tuning.

One of the main drawbacks of the quad beam is its large size compared to the Yagi beam. Previous efforts to reduce the size of the quad have utilized systems of inductive tuning. Loading coils have been used on one or two sides[1] or in the corners. Linear inductors on the vertical sides have also been used.[2] The purpose of this article is to explain a simple method of capacitive tuning to reduce the size of the quad. The C-T (capacitor-tuned) loop is diagrammed in Fig. 17.

It is well-known that the physical size of the dipole antenna can be reduced by replacing a portion of the antenna with a capacitive body and adding an inductor to restore the system to resonance. It seems less well-known that the full-wave loop antenna also may be reduced in physical size while holding the resonant frequency of the system constant by adding capacitance at the voltage loops. No inductors are needed. The capacitance may be added by any of the methods shown in Fig. 18.

The outside dimensions of the C-T loop may be anything chosen by the builder with the larger limit being the full-size, full-wave loop. The limit on the amount of size reduction effectively attainable depends both upon the electrical resistance in the circuit and upon the tendency in loop antennas for the current to become equal at all points in the circuit when the loop becomes very small in proportion to the free-space wavelength at the frequency under consideration. The geometrical shape of the loop is unimportant to basic operation provided that the capacitance is placed at or between the voltage loops. The bottom half of the chart in Fig. 21 shows the effective dimensional range of the C-T loop. The top half shows the tuning range that can



A winter snow sets the scene and accentuates the diamonds of the C-T quad-beam antenna at W7WKB.

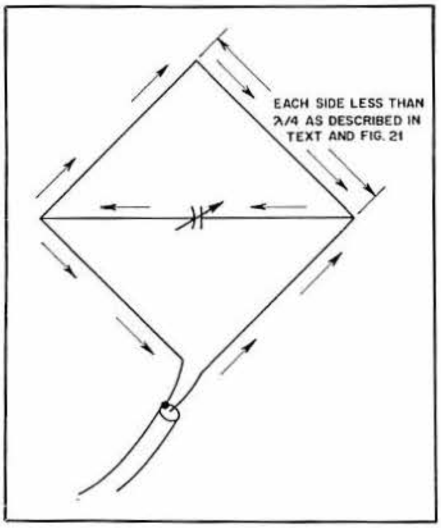


Fig. 17 — The C-T quad design with arrows indicating current flow for 1/2 cycle. The center capacitor is located at the minimum-current (highest-voltage) point in the loop. Each side is less than 1/4-wavelength long. See text and Fig. 21.

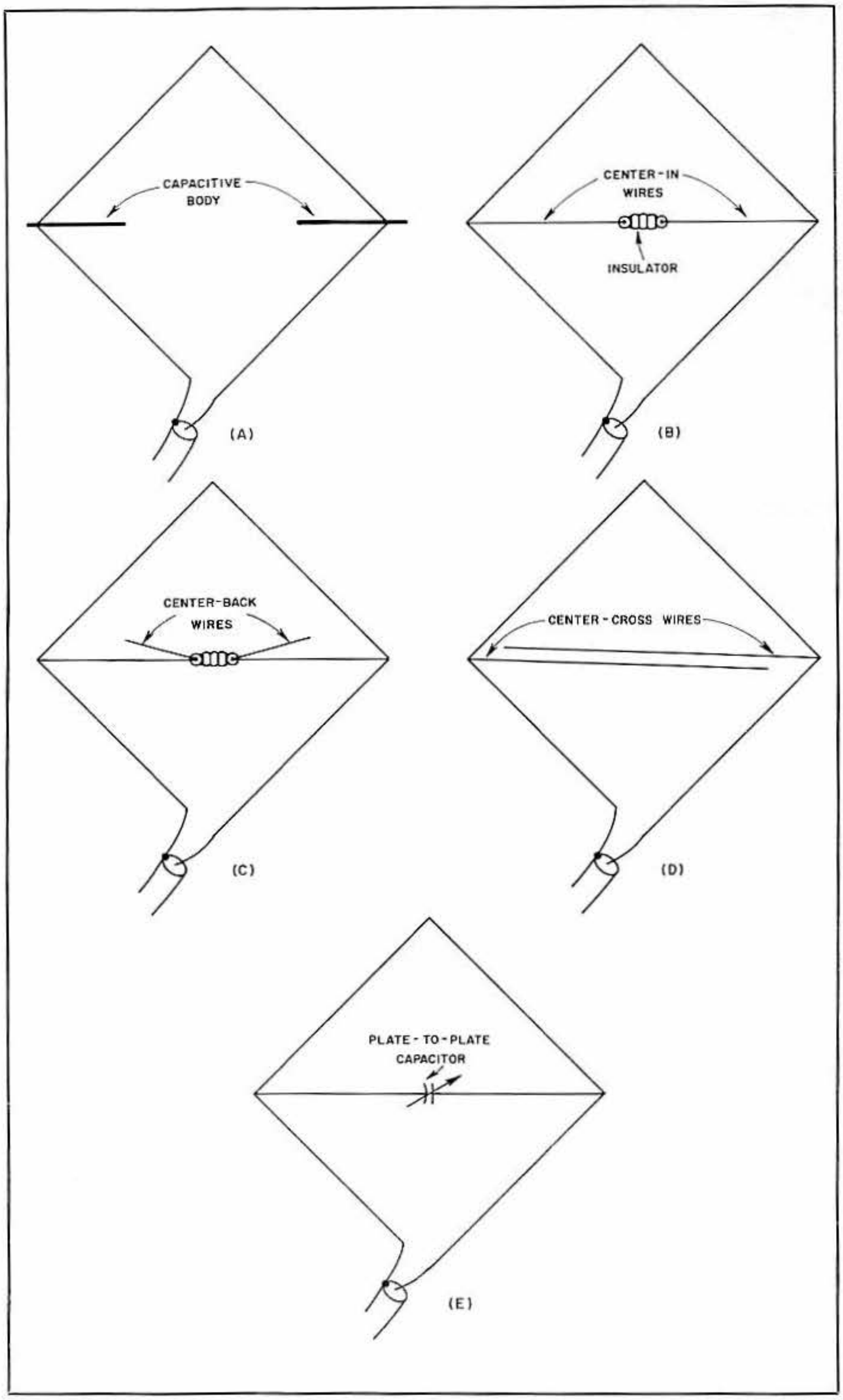


Fig. 18 — Methods of adding capacitance to the C-T loop are shown here. In Fig. 18C, if the center-back wires are placed too closely to the center-in wires, they become ineffective. A 12-inch (0.3048 m) spacing from the end of the center-back wire to the center-in wire is satisfactory. Wires running back toward the loop center may be attached to the outside ends of the center-back wires if more capacitance is needed. In Fig. 18D, the capacitance added by the center cross wires varies with both the length of wire and spacing between wires.

be expected by using various methods of adding capacitance to the diamond quad. These dimensions are intended as guidelines only.

The feedpoint resistance of the full-size, 1-wavelength loop is about 100 ohms. The feedpoint resistance of the C-T loop decreases as it is made smaller but will offer a good match to a 50-ohm coaxial line over the entire usable range as shown in the chart. A gamma match may be used if an exact match is desired.

More than one C-T loop may be used to form the C-T quad beam. A parasitic reflector was used in this installation because of the higher radiation resistance attainable while maintaining good gain. Maintaining the radiation resistance as high as possible is particularly important in small beams, both to keep efficiency high and to prevent the bandwidth from becoming too narrow.

Tuning and Mounting

The use of a grid-dip meter to attain initial band resonance is very helpful. By using a grid-dip oscillator, this beam was tuned initially with the driven element to resonate at the center of the band of interest. The reflector was then tuned to resonate at a frequency three percent lower than the driven element. Final adjustments were made using a test oscillator located about 1000 feet (300 m) away as a reference signal.

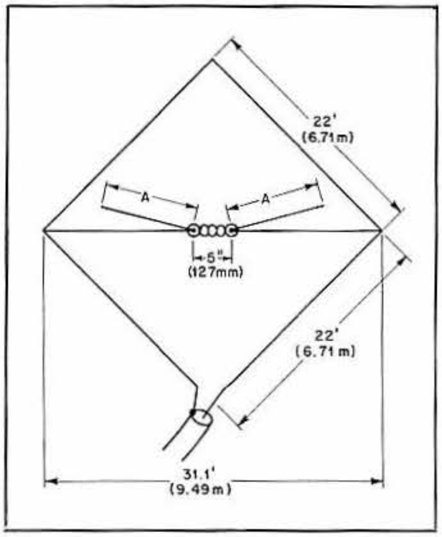


Fig. 19 — Dimensions for the 40-meter C-T quad are shown above. For the 2-element beam the spacing between the driven element and the reflector is 20 feet (6.10 m). The length of the center-back wire (dimension A) is 12 feet, 9 inches (3.89 m) for the reflector, and 9 feet, 11 inches (3.02 m) for the driven element.

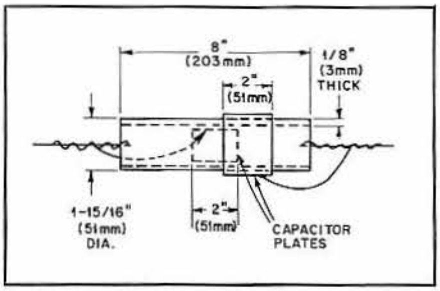


Fig. 20 — A variable capacitor is illustrated here. It can be used to tune the C-T quad. The eight-inch (203-mm) tubular portion is made from plastic water pipe. The cylindrical capacitor plates are formed from a copper sheet. One plate slides inside the eight-inch (203-mm) tube and the other over the outside of the tube. Maximum capacitance is approximately 25 pF.

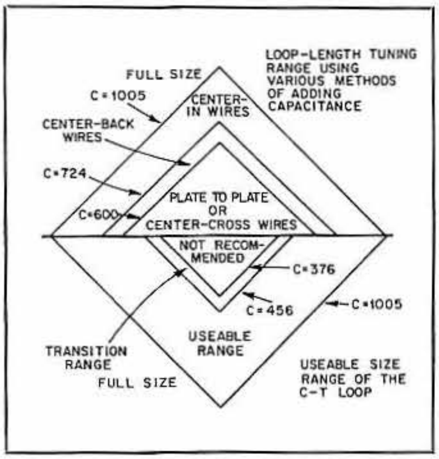


Fig. 21 — The chart shown above, providing dimensional guidelines for a single C-T loop, is based on the equation LF = C, where L is the outside dimension in feet, F is the frequency in MHz, and C is a constant chosen for the size of the C-T loop to be constructed. Use the largest size possible for the best electrical results. This is particularly true when using C-T loop elements to form a parasitic beam.
To use the chart, pick the largest C (up to C = 1005) feasible for your application. Use bottom half of the chart to see if the C-T loop will operate at the dimensional size selected. Then refer to the top half of the chart for the recommended capacitance method.

Table 3

Data for plotting SWR curve. Information in this table is used for plotting the SWR curve for the 40-meter C-T quad beam, as described in the text.

Frequency (MHz)	*SWR*
7.500	4.87
7.450	4.00
7.400	3.08
7.350	2.33
7.300	1.82
7.275	1.78
7.250	1.94
7.200	3.44
7.150	5.25
7.100	8.08

The director was tuned for lowest SWR and the reflector for best gain. If you lack a grid-dipper, initial resonance can be established by listening to your station receiver for a strong signal while making the adjustments. A dramatic increase in signal strength will be noticed at resonance. Tuning is accomplished by shortening or lengthening the capacitance wires.

The single loop or beam may be mounted either horizontally or vertically for horizontal or vertical polarization, but in either case it should be mounted as high above the ground as possible. Loop antennas operating close to ground will show a much higher feedpoint resistance than normal and will waste considerable power in groundheating effects. A rough guideline is to mount the antenna so that the bottom point is at least half the loop diameter above the ground.

The working 40-meter version of the C-T quad beam had a diamond configuration because of the greater mechanical strength and because of the longer center wire for tuning purposes. Final dimensions are shown in Fig. 19. A good quality center insulator should be used because of the high voltages present at the center.

A tubular tuning capacitor was originally installed in the driven element and worked well until the kW power level was reached. It then promptly arced over, leaving a conductive carbon deposit. A version using 2-inch (51-mm) plates as shown in Fig. 20 adequately tuned the reflector even at the kW level for some time. The capacitors, as shown, were not tried under wet conditions, but would probably be satisfactory at power levels up to 400 watts. For long-term use, the method shown in Fig. 18D is preferred over plate-to-plate capacitors because the high voltages are handled more easily.

Because some dielectric heating was noticed in this capacitor, the wire-tuned version was adopted. The wire version is recommended over the methods shown in Fig. 18D and 18E, any time the loop is large enough to be tuned by no more than one doubled-back wire (as shown in Fig. 18C). Tuning wires eliminate the capacitor with its heat loss and allow somewhat better current distribution. Less center radiation occurs because of partial canceling effects in the doubled-back wires. It would be wise initially to cut each center-back wire 12 inches (0.31 m) longer than shown to allow tuning. Pruning each center-back wire by 1 foot (304.8 m) increases the resonant frequency by roughly 100 kHz in the 40-meter version. No. 14 Copperweld wire was used throughout.

Performance

The antenna described performed up to expectations and has prompted many complimentary reports. The SWR curve information shown in Table 3 was attained using a 75-ohm coaxial feed line without any matching network. The SWR would be lower if a 50-ohm line or if a matching network were used. Forward signal strength as compared to the strength to the rear showed a maximum 30-dB difference as measured by means of the receiver S meter. Typical difference, as finally adjusted, was 12 dB.

The gain of the C-T quad over a comparable double Zepp (full wave on 40) was typically at least one S unit better when both antennas were at a height of 45 feet (13.7 m). The Zepp was better on very short skip but the C-T quad consistently was favored on longer skip. When elevated to 65 feet (19.8 m), the C-T quad gave outstanding results. At this height, two S-units improvement over a vertical antenna at distant points was noted many times.

The C-T quad may be built for any band. It should be most useful in meeting requirements for an inexpensive easily tuned wire-beam antenna where the full-size quad is unsuitable for mechanical or economic reasons. This material was orginally presented in *QST* by Roger Sparks, W7WKB.

References

[1]Pinner, "The Short Quad," *QST*, February 1964.
[2]Courtier-Dulton, "Some Notes on a 7-MHz Linear-Loaded Quad." See Chapter 4.

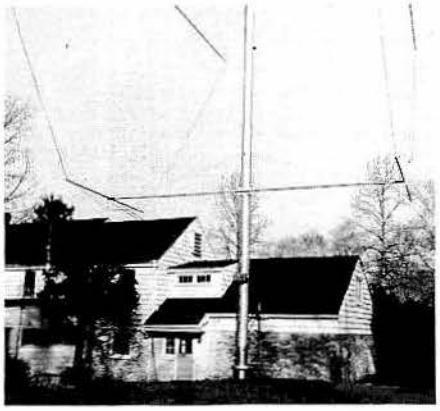
A Nearly Full-Size, Rotatable, 2-Element Quad for 80 Meters

We don't expect readers to rush right out and duplicate this antenna system — but this doesn't mean a lot of hams wouldn't like to!

Many hams have been thinking about new 80-meter antennas to improve their DX capabilities. On the higher amateur frequencies, antenna gain is relatively easy to acquire with a compact Yagi or quad. It is much harder in this respect on 40 meters. On 80 meters, however, the problem of securing any increase in antenna gain over a conventional dipole or groundplane is very difficult indeed, particularly where space is limited. Rhombics, Vs or multi-element collinear arrays become completely impractical on the normal urban or suburban lot. Even a phased vertical array is hard to handle on a city lot, and too often, performance is marginal because it is impossible to install an optimum ground system at such a location.

The author solved this problem at his QTH by constructing an almost full size 2-element quad for 80 meters. A unique tuning arrangement permits this antenna to be operated at any frequency within the 80-meter band with an SWR of close to 1. While certainly not adaptable to every individual's situation or pocketbook, a description of this antenna should be of interest to many amateurs. As far as it is known, this is the first and only set of beams, on one rotatable tower, covering all bands from 2 to 80 meters. By connecting the 2 quad elements in series to form a rotatable, bidirectional loop, the frequency coverage has been extended to 160 meters.

At this point, a few comments might be in order on the circumstances which led to this sizeable 80-meter antenna project. In June 1965, the writer returned to ham radio activity after a QRT of almost 30 years. During the first year of operation, the antennas of K3JH were a conventional commercial tribander for 10, 15 and 20 meters mounted on a 60-foot (18.3-m) tilt-over tower, and a trapped, inverted V for 40 and 80 meters. A bit of DX chasing soon led to the conclusion that better antennas were needed. Since the QTH is on a suburban lot about 175-feet (53.3-m) square, and heavily wooded, a "Christmas tree" array seemed the best alternative. Consequently, in the summer of 1966, with a great deal of help from Bob Scully, W2FXN, a 115-foot (35-m) rotary tower was installed along with full-size monoband beams for all bands from 2 through 40 meters.



The bottom support of the quad elements is shown in this view, along with the tuning-network box, which is mounted on the mast.

This rotary steel tower is 16 inches (0.41 m) OD at the base with 1-inch (25-mm) thick walls. The tower rests in a 1/2-inch thick steel bearing-tube 15 feet (4.57 m) long and 20-inches (0.51-m) OD. The bearing tube is imbedded in a block of concrete 8 × 8 × 16 feet (2.44 × 2.44 × 4.88 m) which weighs 70 tons. The tower tapers to 5-1/2 inches (140 mm) at the top, and was designed to carry nine full-size monoband beams through 125-mph winds.

Initially, the antenna complement was as follows

2/6meters — Vert. groundplane at 115 feet (35 m)
6 " — 6 el at 113 feet (34.5 m)
2 " — 15 el at 109 feet (33.2 m)
20 " — 5 el at 104 feet (31.7 m)
15 " — 5 el at 96 feet (29.3 m)
10 " — 6 el at 86 feet (26.2 m)
40 " — 3 el at 77 feet (23.5 m)

A rotary ball-bearing ring and clamp at the 70-foot (2.13-m) level on the tower was used to support one end of an inverted L for 80 meters. This long wire, which could be used also on the higher frequencies, was fed through a Matchbox at the base.

Performance on 40 through 2 meters with this antenna system was generally excellent. The L and inverted V on 80, however, left much to be desired, especially when compared to the antenna performance on the other bands.

In attempts to improve this situation, several different 80-meter antennas were installed at various times between 1966 and the spring of 1969. Included in this effort were a top-loaded groundplane and a pair of phased verticals. None of these antennas provided sufficient improvement in DX performance on 80 to be considered satisfactory.

With the advent of the 5-Band DXCC, the question of how to do better on 80 meters again became a matter of concern. It was at this time that the concept of a quad of some sort, to be mounted on the rotary tower, began to emerge. Since 40-meter quads had been constructed previously, and were mechanically feasible, the thought at first was to build a half-size quad for 80 meters, using loading coils. Preliminary calculations indicated the possibility of achieving some gain over a dipole in addition to the obvious advantage of being able to rotate the array.

It was quickly determined that a half-size quad mounted at 57 feet (17.4 m) would fit underneath the 40-meter Yagi. Construction could be quite conventional using fiberglass X frames in each element, and a spacing of 0.15 wavelength.

Design Considerations

The proposed design was discussed with a number of amateurs including Jim Lindsay, W0HJ, Dunc Carter, W5IOU, and Claus Moeller, DL7CM, who were most helpful with advice and suggestions. A search of the literature disclosed that a number of loaded antennas of various types had been built. In most cases, however, performance had been judged empirically, and there was little in the way of specific comparative data on the performance of loaded versus unloaded configurations, or versus a reference dipole. Because of this, the decision was made to build and test a 14-MHz model of a half-size quad. This would enable a direct comparison between the performance of a miniaturized quad and other antennas. Of particular interest was a comparison with a dipole, since this was the more normal antenna used by amateurs on 80 meters.

Henry Pemberton, W3PN, who had become interested in the project, provided the X frames and supports from an old 20-meter quad, for use in the test model. Tom Consalvi, W3EOZ, provided some suitable coil stock for the test design. With this help, the 14-MHz model was quickly constructed. No trouble was experienced in pruning the coils and resonating the loops. Except for one bad piece of insulation on one coil, which promptly burst into flame when rf power was applied to the antenna, the driven element could be fed with a full kilowatt at an SWR of 1. The SWR, however, would rise sharply when the coils, which had no protection from the weather, became wet from rain. All testing, therefore, had to be done on dry days.

Since the 80-meter version was to be mounted on the tower one-quarter wavelength above ground, the 14-MHz model was mounted for the tests at the same relative height. Standard procedures for tuning up the quad were used, and will not be detailed here. Impedance of the loaded loop was measured at 60 ohms, so it could be driven nicely with a 50-ohm line. The bandwidth was 125 kHz, measured between frequencies each side of the resonant frequency where the SWR was 3:1. This was the result expected, due to the heavy loading.

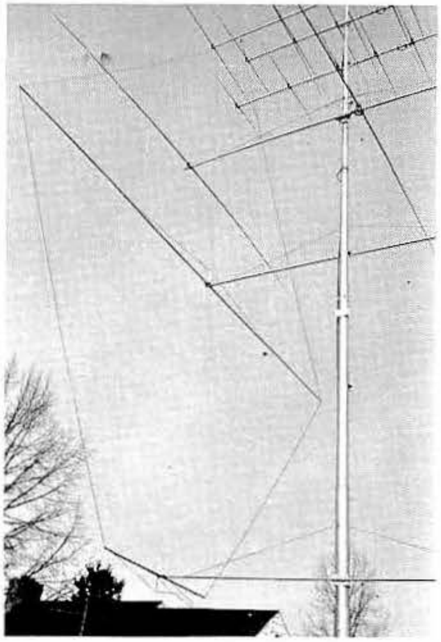
Extensive on-the-air comparisons were made between the model and various other antennas. These included a dipole at the same height above ground as the model, a 3-element tribander at 60 feet (18.3 m), two different inverted Vs at 50 feet (15.2 m) and a 5-element monoband Yagi at 104 feet (31.7 m). The regular antenna switching arrangements in the station were such that almost instantaneous comparisons could be made between the different antennas, minimizing QSB differences in the receiver. In the transmit mode, many amateurs compared signal differences between the test model and the other antennas. It is impossible to list the calls of all those who helped in this way.

After considerable testing, adjustment, readjustment, and minor configuration changes in the model, the results were found to be quite discouraging. The simple conclusion was that a loaded half-size quad had insufficient gain compared to a dipole to warrant proceeding any further with an 80-meter version.

Further Exploration

Before abandoning the 80-meter project, however, we decided to explore some practical ways to increase the size of the elements, preferably without using the normal-type quad X frames, which would be difficult if not impossible to handle when the antenna grew too large. This thinking developed the concept of using the 14-MHz boom at 104 feet (31.7 m) to support diamond-shaped elements at the top, and using a boom and spreaders rather than an X frame to hold the elements at the center. The bottom of the quad elements could be supported easily with a relatively light boom and spreaders near the base of the tower.

In order to reduce the size of the center boom and spreaders, the first model was kite-shaped with an included angle at the top of about 50 degrees. Unfortunately, the results were poor, and compared to a dipole there was no gain. We concluded that this configuration was so squashed together that the antenna was acting like a dipole instead of a quad. A series of configurations was then drawn up on paper. The boom and spreader sizes were varied, but the included angle at the top of each diamond element was kept at 75 degrees or more. This helped to pin down a configuration which would be mechanically feasible, and which would be a reasonable compromise among the various considerations to be taken into account. The one selected is shown in Fig. 22.


A detailed view of one of the quad elements, showing the method of supporting the loop.

Because these elements are almost full size at 4 MHz, making a 20-meter model quite large, it was decided to build and test a model of this configuration on 15 meters. The test procedures for this model were the same as those previously described for the 20-meter model of the half-size quad. This model showed substantial gain compared to the reference dipole at the same height. Also, the model mounted only 15 feet (4.6 m) above the ground compared favorably in performance with the tribander at 60 feet (18.3 m). The 5-element monobander at 96 feet (29.3 m) consistently provided better gain, as was to be expected. The impedance of the driven element was about 80 ohms. Bandwidth between SWR points of 3:1 was 250 kHz, or about twice what was measured on the half-size model.

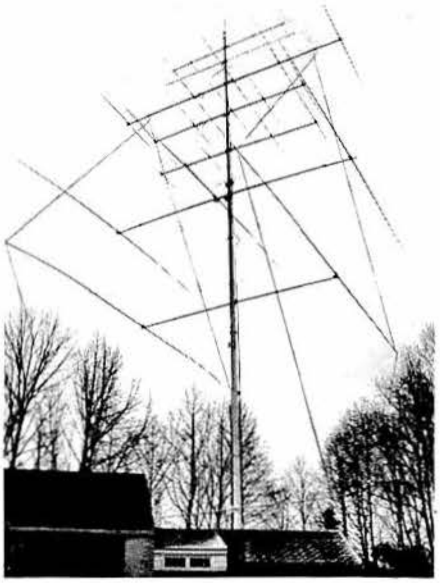
Mechanical Considerations

After a lengthy test period, during which many on-the-air comparisons were made, the results were good enough to make the decision to build an 80-meter version of this antenna. Because of the size of the proposed antenna, considerable thought had to be given to the mechanical design to assure longevity comparable to the other beams which are rated for 125-mph winds. The wire in the quad elements is no. 12 stranded copperweld. All other metal in the antenna is aluminum or stainless steel. The two quad elements are suspended from the 20-meter boom at 104 feet (31.7 m). The insulators are five glazed porcelain knobs. Spacing is one-eighth wavelength, 36 feet (10.97 m). The 20-meter boom is 46 feet (14.02 m) long, and is made from 4-inch (102-mm) OD, 1/4-inch (6-mm) wall T-6 aluminum tubing at the center, and similar material tapering from 3-1/2 inches (89 -mm) to 3-inch (76-mm) OD at the ends. A 1/4-inch stainless steel cable supports the boom 18 feet (5.49 m) out from each side of the tower. Originally, the plan was to slide the quad elements down this cable from the tower. Unfortunately, the steel plates holding the Yagi elements to the boom on the other beams were found to be rusting because of poor plating. Rather than dismantle the beams, a crane was brought in so that these plates could be cleaned and painted by a man carried up in a boatswain's chair. At the same time, the elements were hung from the 20-meter beam, and the center boom and spreaders for the quad were installed with relative ease.

Dimensions

The 36-foot (10.97-m) center boom at the 57-foot (17.37-m) level of the tower is made of a single 24-foot (7.32-m) section of 3-1/2-inch (13-mm), 1/4-inch (6-mm) wall, T-6 tubing with 7-foot (2.13-m) sections of 3-inch (76-mm) OD pipe telescoped and bolted at each end. The boom is supported from the tower with a 3/16-inch (4.76-mm) stainless-steel cable. The spreaders at each end of this boom are 70 feet (21.34 m) long. Each consists of a 24-foot (7.32-m) piece of 2-1/2-inch (64-mm) OD, 1/8-inch (3-mm) wall, T-6 tubing at the center, with two short pieces of 2-1/8 × 1/8-inch (54 mm × 3-mm) tubing telescoped and bolted at each end to make up a length of 30 feet (9.14 m). To complete the spreaders, 20-foot (6.10-m) sections of 1-1/2- and 1-1/4-inch (38- and 32-mm) fiberglass poles are attached to each end of the aluminum centerpiece. Use of the fiberglass reduces weight and eliminates a one-quarter wavelength piece of metal from the middle of the quad element. A 1/8-inch (3-mm) cable and strut supports each spreader to minimize sag, which is very slight as may be noted in the photograph. A welded aluminum T structure and stainless steel clamps are used to hold the spreaders on to the ends of the boom. A stainless steel clamp and Teflon grommet is attached to the ends of each spreader to hold the element wires in place. The only function of the spreaders is to hold the two opposite sides of each quad element apart without too much fore and aft flopping around when the antenna is rotated. The length of the spreaders, wind loading, and safety factor dictates the heavy mechanical design.

The lower boom, which is 23 feet (7 m) off the ground, is made of a 24-foot (7.32-m) section of 2-1/4 × 1/4-inch (57- × 6-mm) T-6 tubing with shorter 2- × 1/4-inch (51- × 6-mm) pieces telescoped and bolted at each end to make the total length of 36 feet (10.97 m). To maintain symmetry, 17-foot (5.18-m) spreaders are attached to each end of the lower boom. These spreaders are made of 1-1/2-inch (38-mm) fiberglass. They are attached to the boom with aluminum angles and stainless-steel clamps. A light stainless-steel cable and strut holds the lower spreaders firm against the pull of the quad-element wires, which are attached to each end of the lower spreaders with stainless-steel clamps. The wires are taped along the fiberglass almost to the center of the spreaders, and then go off at right angles to the tuning box, which is mounted on the tower 13 feet (4 m) above ground. The distance from the end of the lower boom to the tower is about 18 feet (5.5 m), and the 36 feet (11 m) of wire which connects the quad proper to the tuning box represents loading.



Here is the complete antenna system, 2 through 160 meters, all rotatable, directional arrays.

Tuning

Each element, including the 36 feet (10.97 m) of connecting wire just mentioned, resonates at 4050 kHz. Thus, a small amount of additional inductive loading is required to tune the antenna to resonance within the 80-meter band. This is accomplished by putting two relatively small motor-driven coils in series with each loop of the antenna. The reversible motor for each pair of coils in each loop is controlled by a two-way toggle switch mounted on the antenna control panel in the shack. In the case of the driven element, tuning is accomplished simply by applying power to the antenna and then adjusting the loading inductances by the motor-control switch to the point where the SWR is minimum, usually very close to 1. Tuning the reflector can be accomplished by turning the back of the quad toward a distant signal, and adjusting the reflector loading coils for minimum received signal. This seemed a bit cumbersome to do each time the operating frequency was changed from cw to ssb and vice-versa, so a microswitch was added to the reflector coils and motor assembly. Each revolution of the coils flicks the microswitch, which actuates a light on the control panel in the shack. By counting the blinks of the light, and referring to a chart which shows the resonant frequency of the reflector versus the number of turns of inductance in the loop, the reflector can be tuned to any desired frequency. With this tuning scheme, it is quite easy to tune the quad for best performance at any point in the 80-meter band. The bandwidth between the 3:1 SWR points is close to 200 kHz, so retuning is required only for large frequency changes within the band. Frequency flexibility otherwise is quite good.

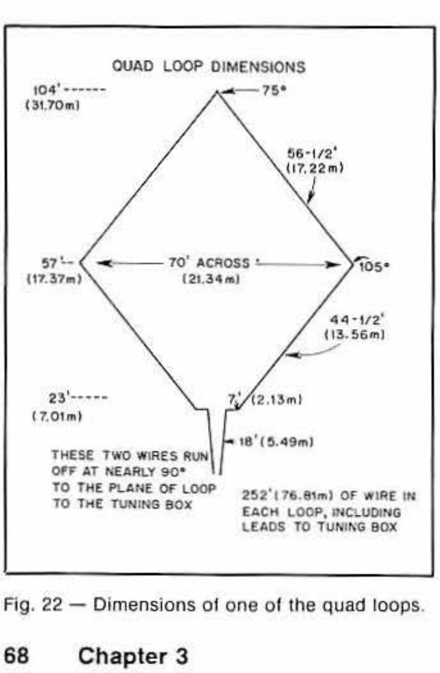

QUAD LOOP DIMENSIONS
104' (31.70m)
75°
56-1/2' (17.22m)
57' (17.37m)
70' ACROSS (21.34m)
105°
44-1/2' (13.56m)
23' (7.01m)
7' (2.13m)
18' (5.49m)
THESE TWO WIRES RUN OFF AT NEARLY 90° TO THE PLANE OF LOOP TO THE TUNING BOX
252' (76.81m) OF WIRE IN EACH LOOP, INCLUDING LEADS TO TUNING BOX

Fig. 22 — Dimensions of one of the quad loops.

The impedance of the driven element measures about 75 ohms. The antenna is coupled to the transmitter through a balun and 50-ohm line. The difference between the resonant frequency of the driven element and the reflector, when the latter is tuned for maximum front-to-back ratio, is in the order of only 1-1/2 percent. This probably results from the quad being only a one-quarter wavelength above the ground. The front-to-back ratio is about 20 dB, and the front-to-side, 50 dB. All measurements have an indicated gain over a dipole in the order of 6 to 7 dB. No degradation in performance, or SWR, has been observed during heavy rain. The small loading coils are protected from the weather, of course, in their aluminum tuner box, so the problem, which was encountered with unprotected load coils in the 20-meter test model, has been eliminated.

Tests were conducted with the second element tuned as a director instead of a reflector; there was no noticeable improvement in gain, whereas the front-to-back ratio was diminished. It is felt that the best results are obtained with the reflector.

Some thought was given to driving both elements at a 135-degree phase difference to obtain a cardioid pattern. It is felt, however, that the conventional quad pattern, with deep nulls on each side, and a reasonably good front-to-back ratio, is more desireable for DX. So, nothing further has been done with such a phasing arrangement.

Results

DX results on 80 meters have improved considerably since the new antenna was put on the air. On cw, the gain seems to drop off somewhat as compared to the phone end of the band. Probably this is due to the fact that the relative size of the antenna is smaller at the cw operating frequencies. Nevertheless, reports usually are from one to several S units higher than other U.S. stations with comparable power input, and conventional antennas. In most instances during pile-ups in a recent cw contest, it took only a call or two to get through, whereas, previously, the station was usually last. It was found also that contacts could be made earlier, as the band opened. In several instances like this, it was amazing to get a response from a DX station, and then to hear other U.S. stations calling without success.

Reports from overseas on ssb are outstanding. During a recent phone contest, several dozen DX contacts were made in just a few hours — everyone on the first call.

During the day, on 80 meters, it is quite easy to work into Canada or the Carolinas with good signals at both ends of the circuit. On a dipole, very often the other station is completely unreadable, if not inaudible. This points up the fact that one notices great improvement in reception with the quad compared to a dipole, which on 80 is just as important as being able to transmit a better signal.

Once it was determined that the quad worked well on 80 meters, the possibility of operating the antenna on 160 meters was explored. Since the loops independently resonated at 4050 kHz, and there was considerable inductive loading available in the coils, it was felt that it might be possible to resonate the antenna on 1.8 MHz by putting the two loops in series. Actually, with the load coils tuned to minimum, the series-connected loops resonated at 1775 kHz because of the mutual coupling. By shortening out the coils entirely, the pair of loops were resonated at 1805 kHz. Therefore, the SWR at the low end of the 160-meter band is very low.

Domestic reports on 160 meters have been excellent. Consistent directional effects have been noted by several observers when the two-turn loop is rotated. The pattern is the typical figure eight, with deep nulls off each side of the loop. It remains to evaluate how well the antenna works on 160-meter DX.

Following completion of the antenna in September, there have been several severe storms, with winds gusting as high as 65 mph. These velocities barely moved the wires and spreaders around. It is apparent that the heavy construction is adequate to handle the winds of much higher velocity for which the antenna was designed. Although it is probably one of the largest quads in existence, it certainly appears as though it will stay up a long time, even through rough weather.

In conclusion, this project could never have been completed successfully without the help of many domestic and overseas amateurs. Their reports, advice, and assistance will always be appreciated. Although this has been a sizeable and difficult antenna task, a great deal of satisfaction has been derived from carrying it through from concept to on-the-air operation. The simple lesson has been relearned with regard to antennas — that one cannot get something for nothing. Mini-size antennas are better than no antennas, but there is no substitute for full-size antennas if one wants full-size results. This material was originally presented in *QST* by Joe Hertzberg, N3EA.

The Folded Mini Quad

A full-wavelength loop can take a variety of forms. Despite the shape suggested here, the author claims good results.

An unusual type of full-wavelength wireloop antenna is in use here on 2 and 15 meters. The design, which the author had not seen previously, provides an antenna that occupies minimum space; the antenna is omnidirectional, vertically polarized, broadbanded and requires no groundplane.

It evolves from a full-wavelength loop.[1] The loop, if fed on the side (x-y) as in Fig. 23A, radiates a vertically polarized signal. The radiation pattern is bidirectional, with maximum radiation broadside to the plane of the loop and with the highest field strength in the plane A-A′.

The loop can be deformed into a square, such as in the elements of a quad, and without much loss of efficiency into a rectangle (Fig. 23C). Vertical polarization, bidirectional signal pattern and maximum radiation from the plane A-A′ are retained.

A 90 degree bend at A-A′ and two further right angle bends at B-B′ and C-C′ transforms the flat loop into a cube. The circumference is still a full wavelength and each side of the cube measures 1/10 wavelength. Again, vertical polarization is retained, but the appreciable bidirectional radiation from the sides of the cube adjacent to A-A′ leads to a nearly omnidirectional radiation pattern.

My 2-meter antenna was constructed from aluminum clothesline wire; the length in feet was chosen by 1005/f MHz. It is fed with 50-ohm coaxial cable through a Pomona Electronics no. 1699 adapter and no matching device is used. The SWR is less than 1.2:1 from 144 to 146.5 MHz and climbs to 1.4:1 at 148 MHz. The radiation pattern was measured with a simple field-strength meter, using a half-wave dipole as pickup element and a 20-kΩ resistance in series with the 20-μA meter to improve linearity.[2] The front-to-back ratio is 1.8 dB with no prominent sidelobes apparent, but a rather sharp 3-dB dip is caused by the "shadow" of the feed line and hardware.

Performance

Fed with 10 watts and used as an indoor antenna, it gives consistent communication with 2-meter fm base and mobile stations within a 10- to 15-mile radius. It performs better on receive and transmit than a 1/4-wave whip at the same location.

A 15-meter version of the antenna was then constructed and suspended in the attic with string and tacks. It is operated with 100 watts and the rig loads almost as well as the 2-meter version, but with a slightly higher SWR. The first contacts were with California and it has since given excellent performance to the West, Midwest and South as well as to South America and Europe.

The close proximity of antenna sections radiating out of phase may lower the efficiency over that of a loop, yet, in terms of space requirement, construction cost and ease of installation (no radials!) and tuning, the antenna is hard to beat. As a full-wave loop it should have a slight edge over a vertical. The author recommends further experimentation and modification, e.g., into the even more space-saving configuration of a cylinder. This material was originally presented in *QST* by Max Blumer, WA1MKP, SK.

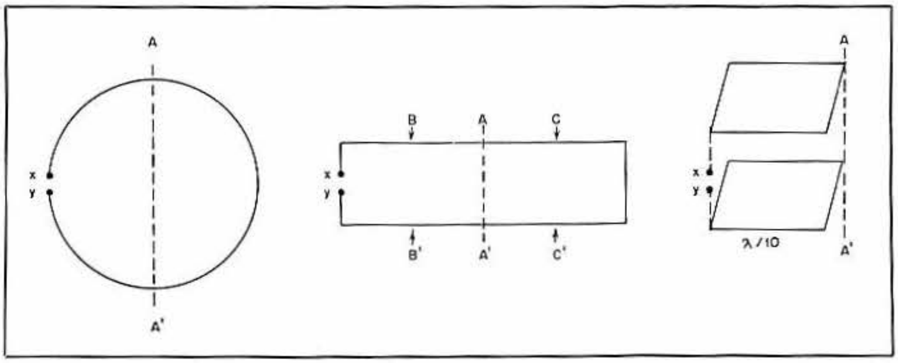


Fig. 23 — Conversion of the full-wavelength loop to the space-saving cubical configuration. The length of the wire and the vertical polarization remain but the pattern changes from bidirectional to omnidirectional. The spacing between the feed point and the adjacent side is not critical. The spacing on 2 meters is about 1-1/2 inches (38 mm), and on 15 meters is about 4 inches (102 mm).

References

[1] *The ARRL Antenna Book*, 13th ed., 1974, p. 65.

[2] *The Radio Amateur's Handbook*, 46th ed., 1969, p. 553.

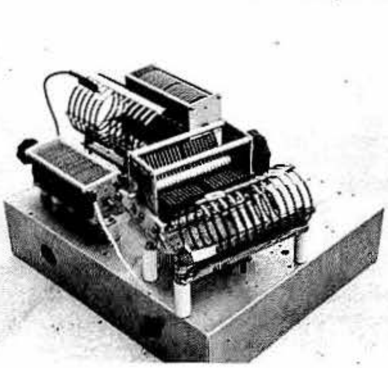
A Convenient Stub-Tuning System for Quad Antennas

The cubical quad has been a popular antenna with amateurs for a number of reasons — relatively light weight, small turning radius, low cost, and good DX performance at rather low heights when compared to other antennas. The authors' experience with quads has demonstrated, however, that best possible performance requires careful parasitic-element tuning. Cutting elements according to various "established" length formulas has often yielded less than satisfactory results. While adjustments for maximum forward gain are generally uncritical, a mediocre front-to-back ratio often results unless time and care are taken to tune the parasitic elements. Factors such as spacing between elements, proximity of the antenna to ground, or influence of other objects (including the other concentric loops in a multiband array) require that the electrical length of the parasitic elements be adjusted using empirical methods if optimum performance is to be realized from the system. It was felt that if one was going to the trouble of erecting a good antenna system, it was worth seeing to it that the antenna was delivering the performance of which it was capable.

These considerations led to the development of the parasitic-element tuning system described here. While the scheme is applicable to quads in general, whether rotary or fixed, the original intended application was in a fixed two-element, full-size 40-meter quad. The descriptions here apply to this 40-meter system, but the general information allows one to follow the same scheme with a quad for any band.

A 40-Meter System

This 40-meter antenna consisted of two non-rotatable full-wave wire loops suspended from a boom which was mounted near the top of a tower. Spacing between elements was 22 feet (6.71 m). The corners of the loops were tied down to convenient anchor points by means of ropes, thereby eliminating the need for spreaders. With the elements thus fixed in place, the antenna was oriented in one general direction and could not be steered elsewhere. A driven-element and reflector combination was used.


The matching network built by the authors for the modified 40-meter system. Relays, used in the switching circuitry, are not visible. The builder is left to choose a suitable network of his own to meet his operating requirements. Basic design information can be found in *The Radio Amateur's Handbook* or *The ARRL Antenna Book.*

Early experiments with the antenna demonstrated the need for careful reflector tuning. Several trips were made up the tower to alternately prune and add wire to the reflector before the antenna exhibited good performance at the frequencies of interest. But when tuned properly, the quad really performed! In many instances signals which were inaudible while using an 80-foot (24.4-m) high reference dipole were perfectly readable with the quad (at a median height of about 100 feet [30.5 m]). Reception was further enhanced by rejection of unwanted signals off the back of the quad.

Now if only the quad could be made rotatable. . . . Unfortunately, a full-size rotating system (spreaders would be needed) was out of the question. The cost, difficulties of construction and installation, and the severe effects of New England winters discouraged such ideas. The authors, being avid contesters and DXers, were willing to settle for the next best alternative — keeping the fixed quad, but electrically switching its pattern.

The solution involved a tunable stub attached to one of the elements to lengthen or shorten it electrically. With the appropriate stub switched in, the single element could be made to look like either a reflector or director and thus cause the pattern to be reversed. In order that adjustments be made quickly, easily, and from a convenient location (such as the shack or the bottom of the tower), it involved more than the conventional short stub often used with quads. Rather, the situation called for a long stub — long enough to reach the desired remote location — terminated in a variable reactance. Tuning the element, then, involved nothing more than adjustment of the value of reactance which could be provided conveniently by means of a variable capacitor.

The electrical principle is simple. One adds inductive reactance to lengthen an element electrically, or capacitive reactance to shorten it. Typically, the former arrangement is used with quads in a driven-element and reflector combination in which both elements are cut to the same physical length. A stub, shorted at the end, is attached at the center of the bottom section of the reflector. By varying the position of a shorting bar along the stub, the amount of inductive reactance presented to the element can be varied and the electrical length altered correspondingly. Because the stub is short in length, this adjustment must be made at the antenna itself, preferably near or at its final height.

Now, if the stub is cut to some different length which happens to be longer than in the above case, the parasitic element can still be made to see the proper amount of inductive reactance (if it is a reflector) provided the stub is terminated properly with some other reactance (in general, something other than a short). Varying the reactive termination is then equivalent to moving the shorting bar along the conventional stub. This is a consequence of the impedance-transforming property of transmission lines. The long stub can be treated as a transmission line. If we know its characteristic impedance, its length, and the impedance that must be seen at the parasitic-element end of the line, the Smith Chart can tell us what kind of termination is required at the opposite end.

A reflector cut to the same physical dimensions as the driven element — self-resonant at the desired operating frequency — must "see" roughly 150 ohms of inductive reactance at the terminals where the stub is attached. Although little information is available about the use of directors with quads, it is assumed initially that a director, also cut to the same length as the driven element, must see a roughly equal but opposite amount of reactance, or about 150 ohms of capacitive reactance. If one desires to make the termination at the end of the stub a variable capacitor for convenience of tuning, which was the case in the 40-meter system under consideration, the problem can be rephrased slightly: what length of line of a given characteristic impedance is required so that a variable capacitor (a 10- to 350-pF unit was used) causes the parasitic element to see the above reactances? This is easily solved with a Smith Chart. Two somewhat different systems evolved from these ideas. The second, a modification of the first, will be described last.

The design procedure for the 40-meter version went as follows: The driven and parasitic elements were cut to the same length, given by the more or less standard formula, $L = 1005/f$, where L is the length in feet, and f the frequency in MHz. This resulted in a loop circumference of 143 feet, 6 inches (43.74 m) at a frequency of 7.0 MHz. In the practical installation, the loops were triangular in shape rather than

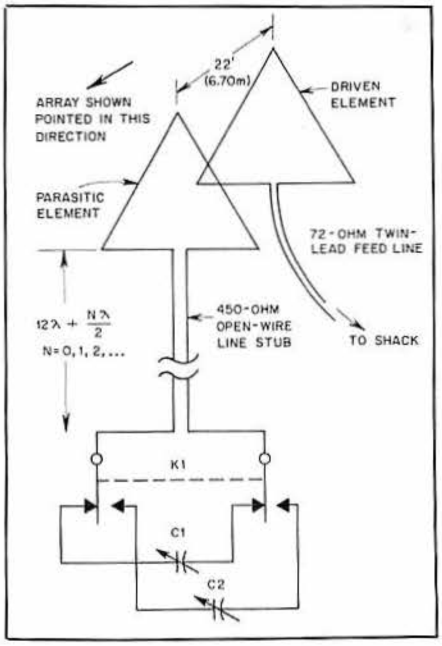

ARRAY SHOWN POINTED IN THIS DIRECTION
22' (6.70m)
DRIVEN ELEMENT
PARASITIC ELEMENT
72-OHM TWIN-LEAD FEED LINE
12λ + Nλ/2
N=0, 1, 2, ...
450-OHM OPEN-WIRE LINE STUB
TO SHACK
K1
C1
C2

Fig. 24 — Configuration of 2-element switchable 40-meter quad. Triangular loops are shown, although square or diamond loops can be used too. Both elements are cut to the same dimensions: 143 feet, 6 inches (43.74 m) for 7.0-MHz operation. The selection of either C1 or C2 by means of K1 determines which direction the array is pointed. Switching components K1, C1 and C2, can be installed inside the shack or on the ground. The stub line is cut long enough to reach them. Feeding the driven element with 72-ohm Twin Lead results in a low SWR.

C1 — 10- to 350-pF air-variable capacitor, adjusted for director operation as described in text.

C2 — Same as C1, except adjusted for reflector operation.

K1 — Dpdt relay (Potter and Brumfield KA11DG or equivalent).

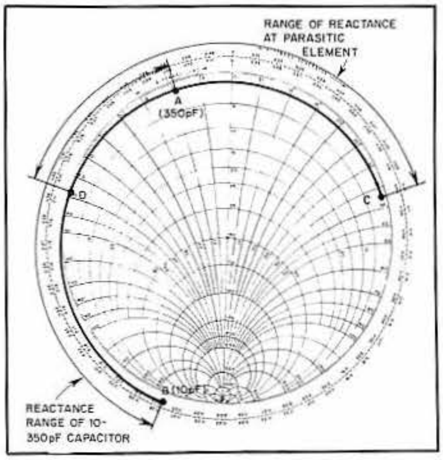


Fig. 25— Example of Smith Chart calculations required to arrive at correct stub dimensions. A 10- to 250-pF capacitor is used as the variable-reactance element which terminates the 450-ohm transmission line used for a parasitic-element stub. The chart is normalized to 450 ohms. The arc between points A and B represents the range of reactance of the capacitor as it is tuned between the extremes of its range. If the capacitor is connected to a 0.12-wavelength long stub (plus any multiple of one-half wavelength) with a 450-ohm characteristic impedance, the range of reactance represented by the arc between points C and D is presented to the parasitic element. This range is sufficient to cause a properly cut parasitic element to look like either a director or reflector. Further discussion of Smith Chart calculations can be found in the latest edition of *The ARRL Antenna Book*.

square or diamond. Shape is relatively uncritical — performance is approximately equivalent for the various geometric configurations, and ease of installation was considered more important. The triangle has the advantage of requiring only three tie-off points — one at the top where it hangs from the boom and two at the bottom — whereas the other two forms require support at four corners. Furthermore, the triangle requires less vertical height — approximately 41 feet (12.5 m) on 40 meters, assuming equal-length sides — as opposed to the diamond which needs about 50 feet (15.25 m). The square requires the least vertical height but is the most difficult to support mechanically. The resultant configuration is shown in Fig. 24.

The stub line was made from 450-ohm open-wire transmission line because of its relatively low cost in commercially made form and its low-loss characteristics. The reactance range of the 10- to 350-pF capacitor by itself at 7 MHz was then plotted on the Smith Chart as shown in Fig. 25. (Recall that $X^L = 2\pi fL$ and $X^C = 1/2\pi fC$ where X^L and X^C represent values of inductive and capacitive reactance respectively, given in ohms, L and C the corresponding values of inductance in henrys and capacitance in farads, and f, the frequency in hertz.) The low-capacitance end of the range is indicated as point B in Fig. 25 with the Smith Chart normalized to 450 ohms in this example, while the other extreme comes out at point A. If the capacitor was then connected at the end of a 0.12-wavelength section of the 450-ohm line (approximately 16 feet [4.88 m] in open-wire line), the impedance seen at the other end of the line would vary between the range of slightly greater than +j300 to -j300, represented by points C and D. This would meet the +j150 and -j150 reactive loading requirements of the parasitic element for reflector and director operation, respectively. Actually a stub length of 0.12 wavelength, plus any multiple of a half wavelength, would work too, because any half-wavelength section of transmission line merely repeats at one end the impedance that appears at the other. Thus, the distance to the desired remote location dictates the minimum required line length. Another advantage of using 450-ohm line, as opposed to a line with a lower characteristic impedance, becomes apparent when working examples on the Smith Chart — for a given capacitor tuning range, the 450-ohm line produces a greater range of reactance change at the antenna end of the line. A 300-ohm line would serve almost as well, however, providing only slightly less tuning flexibility.

The stub was terminated at a dpdt relay which was controlled from the station operating position and which was used to select one of two variable capacitors — one adjusted to provide reactance for reflector operation and the other for director operation, as shown in Fig. 24. In this manner, the pattern could be flipped around 180 degrees instantly from the shack. The driven element was fed directly with 72-ohm transmitting-type Twin-Lead. A low SWR was obtained with no special provisions made for matching.

The director and reflector tuning should be done empirically, as was stated before. Experience has shown that quads tune rather broadly for maximum forward gain. It was found that fairly large changes in the settings of the variable capacitors did not alter the gain significantly. It is best, therefore, to tune for maximum front-to-back ratio, on which the settings had considerably more effect. On-the-air signals arriving from the rear direction can be nulled by tuning the capacitors. The nulls should be fairly pronounced if the

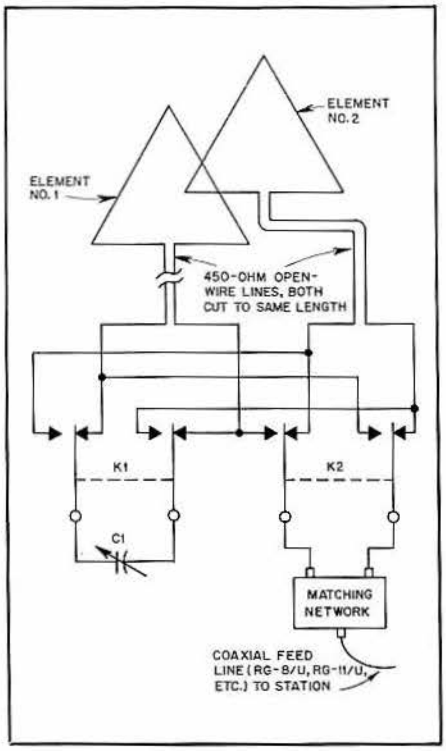

ELEMENT NO.2
ELEMENT NO.1
450-OHM OPEN-WIRE LINES, BOTH CUT TO SAME LENGTH
K1
K2
C1
MATCHING NETWORK
COAXIAL FEED LINE (RG-8/U, RG-11/U, ETC.) TO STATION

Fig. 26 — Configuration of modified 2-element switchable 40-meter quad. The lines from each element are both cut to the same length, which can be the same as the parasitic element line in Fig. 24 or other suitable length. Both elements are cut to the same dimensions as in Fig. 24. The positions of K1 and K2 determine whether an element is fed as a driven element or terminated as a reflector. The array pattern can be switched by determining which element operates as a reflector or driven element. Only one tuning capacitor is required, but a matching network is needed to match a coaxial feed line.

C1 — 10- to 250-pF air-variable capacitor, adjusted for reflector operation.

K1, K2 — Dpdt relays operated simultaneously, or both may be replaced by a single four-pole, double-throw relay (Potter and Brumfield KA11DG or equivalent).

system is set up as described here. The exact amount of attenuation of signals off the back of the antenna varies from signal to signal. It was observed that the 40-meter antenna exhibited the greatest front-to-back ratio for signals arriving from distant locations (at low radiation angles). Alternatively, field-strength measurements can be made to determine the proper settings for minimum radiation or reception off the rear of the antenna. In this fashion, one capacitor is adjusted for director operation and the other for reflector operation.

When making large excursions in operating frequency on 40 meters, it is necessary to touch up the tuning. A director tuned for operation in the low end of the cw segment is self-resonant approximately in the middle of the phone portion and provides little usable gain at those higher frequencies. Retuning is done easily, however — something which is not possible using fixed-tuned elements.

A Modified 40-Meter System

The 40-meter system described above provided very good results over a period of months, including stateside and DX contest work and casual DXing. After some thought, however, a modified system was constructed. The new configuration provided some advantages over the orginal scheme.

The same principle of operation was retained. The new system shown in Fig. 26, used only a reflector-type parasitic element, but the switching system now allowed either element to operate as the driven element or reflector. In this manner, the antenna pattern could still be reversed by choosing the appropriate element for the desired function.

Several factors prompted the change. It was found with the original system that a considerably higher front-to-back ratio could be had using a reflector rather than a director. The latter yielded no more than about 10-dB discrimination against signals received off the back of the antenna, even with careful tuning, whereas with the former the figure was approximately as high as 25 dB. Although most available literature made little mention of quad performance using a director, this observation agreed with what little published data could be found on the subject.[1] The reflector-only model also had the advantage that just one tuning adjustment was required, since one stub reflector served both elements in an identical fashion. Furthermore, because the system behaved the same no matter which direction the array was switched, the SWR did not change when switching, and the transmitter was thus always tuned properly. With the original scheme the antenna feed-point impedance changed when switched between director and reflector operation. Although the resultant SWR was not objectionable in either case (it did change, though), it was necessary to retune the transmitter after switching, or tolerate a moderate amount of mistuning.

The design procedure for the new arrangement is basically the same as before. Both elements are cut to the same length. Only the stub requirements for a reflector need be considered now in doing the Smith Chart calculations. Once the stub line length is determined, two such identical-length lines, both made from the same type of transmission line, are cut, one for each element. A four-pole, double-throw relay, or two dpdt relays operated simultaneously, are required in the hookup shown in Fig. 26, to switch the two lines between the parasitic-element termination and the main feed-line matching network.

The new system has one disadvantage, however. A matching network is required between the transmitter and driven element because of the mismatch between the main feedline, which is presumably coax, and the driven-element open-wire feed line. The original system required no special matching. This presented no problem in the 40-meter system considered here since a suitable network was easily constructed. The builder is left to choose a suitable matching network of his own as there are numerous possibilities to take care of the varied matching requirements which may arise under different situations. Depending upon one's preferences and requirements, the modified scheme may or may not prove more attractive.

Additional Remarks

A few general comments can be made at this point. Although a variable capacitor has been designated thus far as the termination for the stub, there is no reason for not using a coil or some other combination of inductance and capacitance if it will work with a stub length which happens to be convenient. The builder can choose for himself. The 10- to 350-pF capacitor described earlier had approximately 0.05-inch (1.27 mm) spacing between plates. While it is difficult to predict the voltages present in the parasitic element (and across the capacitor), no arcing between plates was observed during transmitting periods, even while running one kilowatt transmitter dc input. This suggested the plate spacing was adequate.

The lines from each element should be brought away perpendicular to the elements as much as possible, and open-wire line should be kept reasonably clear of nearby objects, especially metal ones. Also, the velocity factor of the line being used (0.95 for "ladder" line) must be remembered when computing physical lengths.

The authors erected a single diamond-shaped 80-meter quad loop with its bottom close to the ground. The antenna was tried as both a vertically and horizontally polarized radiator. For DX work, the vertically polarized version yielded unquestionably superior results in terms of greater signal strengths at long distances and the beneficial feature of rejection of unwanted high-angle radiation from stateside stations when receiving. A parasitic element to accompany the single loop was not tried. These observations suggest interesting possibilities for vertically polarized ground-mounted quads for low frequencies.

The ideas presented here are applicable to any quad antenna, but should be especially useful in designing large arrays which cannot be turned physically. The design procedure is simple in any case. The feature of continuously variable tuning eliminates the guesswork in cutting fixed-length, fixed-tuned elements. The system will serve well in any situation where, say, climbing the tower to work on the antenna is not convenient.

A fixed, switchable array is an asset to the contestant or DXer who finds it necessary to change antenna headings in a hurry. From the northeastern U.S., a single such array provides good coverage of Europe and Africa in one direction and of the western U.S. and the Pacific in the other. If two suitable supports spaced a reasonable distance apart are available, two arrays of this type, perpendicular to each other, can provide a wide range of coverage. This material was originally presented in *QST* by John E. Kaufmann, WA1CQW and Gary E. Kopec, K8RX.

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[1] "Technical Topics," *Radio Communication*, February 1973, p. 101.

Some Notes on a 7-MHz, Linear-Loaded Quad

If you like to experiment with antennas, here are enough new ideas about the construction of quad antennas to keep you going.

Most amateurs who have a serious interest in working DX in the 3.5- to 28-MHz bands would like to have antennas providing them with forward gain on all of these bands. Today, a triband trap Yagi or cubical quad may be employed to achieve this objective on 14, 21 and 28 MHz. Rotary beams are, for all practical purposes, out of the question for 3.5 MHz, but it is possible to achieve some gain with a 7-MHz rotary beam without having to pay a fortune for a supporting structure.

The Hy-Gain linear-loaded 2-element Yagi or the Mosley inductively loaded beam for 7 MHz can achieve this objective. The writer, however, prefers quads to Yagis, based on his own experience. Difficulties often arise when one seeks to mount beams for several different bands on the same tower without marked loss of performance on any band. The primary problem is, of course, that a full-sized cubical quad for 7 MHz is a monstrous structure. Such antennas have been erected, but they are not suited for the average amateur with a limited budget.

The first step in building a 7-MHz quad is, therefore, to design a single 7-MHz quad loop of reasonable size which is mechanically strong enough to survive most weather conditions.

Linear Loading

As a general rule, a reduction in antenna size to two-thirds of full size can be effected without a noticeable drop in performance, providing care is taken to limit the losses introduced by the loading devices. This means that one can think in terms of a loop for 7 MHz with 24 feet (7.32 m) on a side instead of 36 feet (10.97 m) on a side. An additional factor in choosing a 24-foot-per-side length was that the longest bamboo spreaders that the writer could obtain were 18 feet (5.5 m). Attempts were made to lengthen these spreaders, but results were not satisfactory mechanically.

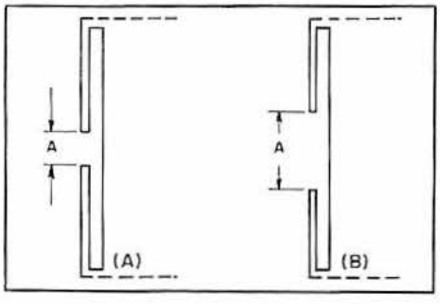


Fig. 27 — A method for linear-loading of one side of a quad element.

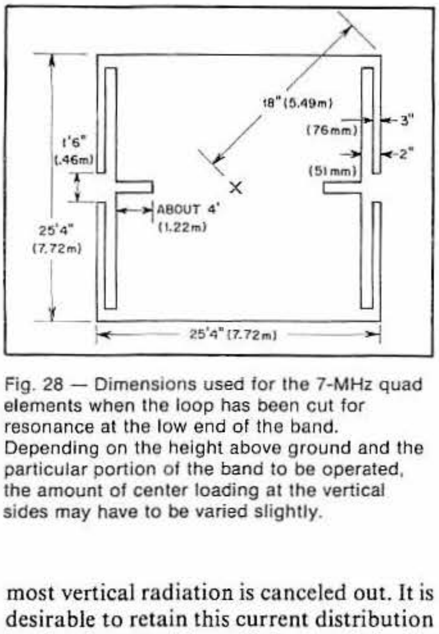


Fig. 28 — Dimensions used for the 7-MHz quad elements when the loop has been cut for resonance at the low end of the band. Depending on the height above ground and the particular portion of the band to be operated, the amount of center loading at the vertical sides may have to be varied slightly.

If a 24-foot loop is to be used, the next questions are where to put the loading and what form of loading to use. A full-sized quad loop has symmetrical current distribution. The current maxima occur in the middle of the horizontal sections, and the current minima develop in the middle of the vertical sections. The current distribution in the vertical elements is such that most vertical radiation is canceled out. It is desirable to retain this current distribution in the shortened loop. It is also desirable not to put the loading in the center of the horizontal elements, since maximum radiation occurs at the current maxima, and it does not make sense to cut out the portion of an antenna that does the most effective work. The writer, therefore, chose to put the loading in the vertical sides.

There are two popular methods of loading, stubs or coils. The writer dislikes coils for loading since, if they are wound with a heavy-gauge wire (desirable in order to avoid undue losses), they are bulky and difficult to weatherproof. The choice was therefore stub loading. It would have been possible to insert a stub at each corner of the loop, tied back to the spreaders. But, the current flowing in such stubs would be unbalanced, and radiation in unwanted directions would take place from the stubs themselves. There is also the consideration that if the same spreaders are used for 14-, 21- and 28-MHz loops, stubs at the corners of the 7-MHz loop would have to be mounted well clear of the loops for the other bands.

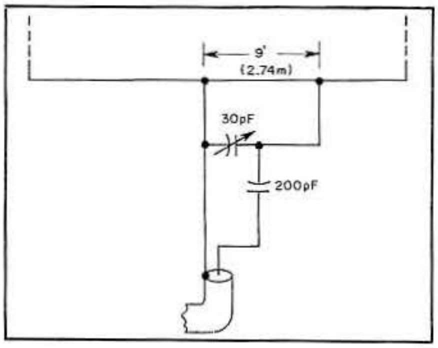
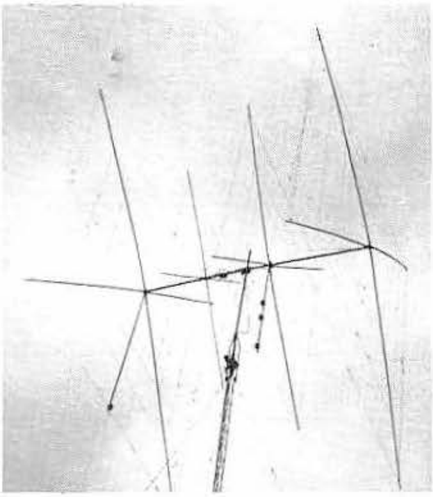


Fig. 29 — Diagram of the matching section used on the 40-meter driven element. The gamma capacitor employs a 100-pF air variable and a 100-pF high-voltage silver mica connected in parallel.

The original linear-loaded 7-MHz quad element was tried by the writer in a four-band quad some years ago. A single stub in the center of each vertical side was used. The loading stubs were made 14 feet (4.27 m) long and were tied on to a point near the center of the boom. Performance of this quad on 7 MHz was excellent, but the 21-MHz quad mounted on the same boom was almost useless, probably due to pickup at 21 MHz by the 7-MHz loop with subsequent reradiation. An attempt was made to find an efficient method of loading which did not involve long stubs "floating around." The next step was to try folding the wires in the vertical sections back on themselves as shown in Fig. 27A. Current distribution either side of the center part of the vertical elements is symmetrical, as desired. This change resulted in a loop that was resonant near 7 MHz, although its resonant frequency was slightly high. Shortening of the stubs slightly, as shown in Fig. 27B, was tried. This had virtually no effect on resonant frequency. This is no doubt because the increased end-loading effect of the portion A almost equalled the reduction in stub length. Short stubs (abour 4 feet [1.22 m] long) were then



G3FPQ's compact 4-band quad has 2 elements for 7 MHz, 3 elements for 14 MHz, and 4 elements for 21 and 28 MHz. Pairs of Yagi-type directors are used in place of the usual loop director for the three higher frequency bands.

inserted at the center of the vertical sides, at right angles to the vertical sides as shown in Fig. 28, and resonance at 7 MHz was achieved.

A four-band quad for 7, 14, 21 and 28 MHz was then constructed. Much to the writer's delight, there appeared to be no noticeable interference with the pattern of the 21-MHz quad by the 7-MHZ elements. The loading effect of the stubs would be different at 21 MHz since they would include current maxima; the result is to give a loop which, while resonant at 7 MHz, does not appear to have a third-harmonic resonance in or near the 21-MHz band.

Yagi-Type Directors

The reader can probably see from the photograph that the directors for 14, 21 and 28 MHz consist of pairs of stacked Yagi-type elements level with the driven elements. There are two pairs of Yagi directors for the 10- and 15-meter elements at approximately 6-foot, 6-inch (2 m) spacing, and one pair of Yagi directors for 20 meters at approximately 13-foot (4 m) spacing. The overall length of the directors is 31 feet, 3 inches (9.52 m) on 20 meters; 20 feet, 10 inches (6.35 m) on 15 meters; and 15 feet, 2-1/2 inches (4.63 m) on 10 meters. Performance of the author's array on 10, 15, and 20 meters at the moment is little, if any, better than an ordinary 2-element quad. The writer has only recently had an opportunity to start checking out the directors to see what adjustment they need. Current indications are that they require lengthening, but there is a good deal more experimental work to be done. Anyone who wants to try this system must be prepared to do a good deal of cut and try to tune the directors, if any real increase in performance over a standard two-element quad is to be achieved.

One also has to bear in mind that when dealing with multiband quads the resonant frequency of Yagi-type directors is likely to be affected to a far greater extent by the proximity of other elements than would be the case for a quad-loop director. This is because a Yagi director is a comparatively high-Q element. From the theoretical point of view, the drawback to quad-loop directors is that the reactances involved are such that there is a comparatively low degree of mutual coupling between the quad-driven element and the quad-loop director. This, of course, reduces the efficiency of the loop as a director. This problem should not apply to the same extent with Yagi-type directors, and, in theory at least, they should prove to be more efficient than quad-loop directors. The question now is whether practice follows theory or not. This writer won't have an opportunity to conduct any detailed experiments until the summer. When deciding the original length for the Yagi directors, allowance was made for a rise in frequency of approximately 100 kHz. But, the only way to cope with the effects on the director resonant frequency of the proximity of other elements is by field-strength measurements, coupled with a good deal of cut and try. As in any multiband quad, separate feed lines should be used for each band to minimize interaction between bands.

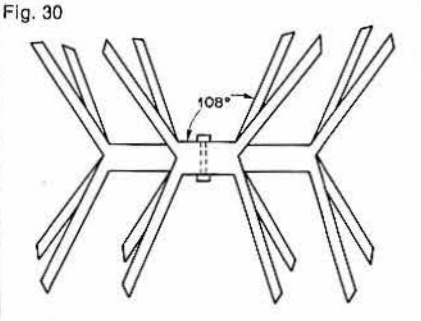
The author's quad has been up for six months now, and final tuning remains to be done to the 7-MHz reflector loop to achieve maximum front-to-back ratio. But the results, even on a cut-and-try basis, are well worth the work that went into the array. This material was originally presented in *QST* by David. L. Courtier-Dutton, G3FPQ.

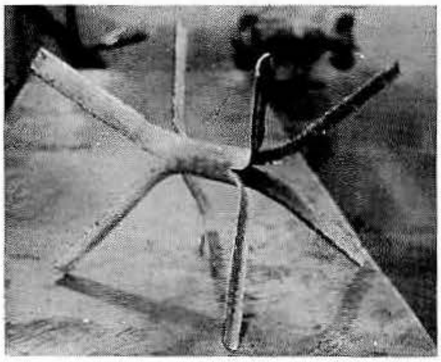
Spider Quad Mount: Simplified

There seems to be a growing interest in the spider quad. The photograph shows a version of a hub or "spider" mount. Using a 2-foot (0.61-m) length of 2-inch (51-mm) diameter steel pipe, a mount can be constructed easily. Two cuts, 10 inches (254 mm) long, are made through the diameter at each end of the pipe. This leaves 4 inches (102 mm) in the middle for the boom. The cut ends are then bent to an angle to suit the desired spacing. The unit shown in the photograph is bent to 108 degrees. The spreaders may be attached to the boom mount with hose clamps, bolts or wire.

The beauty of this design is that it can be made to any size desired. Also, it can be enlarged to a 4-element version, as shown in Fig. 30.

Fig. 30





One of these spider mounts is in use at KP4DJI (constructed by KP4DIO and KP4DJI) using bamboo spreaders. The results have been excellent. This material originally presented in *QST* by Lynda B. Crowley, KP4DIP.

Two-Band Quad Matching

While experimenting with a 2-element, 2-band cubical quad antenna the problem of matching the antenna to a 50-ohm transmission line arose. The antenna is a "plain vanilla" quad built around information in W6SAI's book, *Quad Antennas.* The author's method of feeding the antenna *did not* produce fantastic front-to-back ratio or forward gain. It merely made the standing-wave ratio more acceptable to the 32S-3B used at the home QTH.

After building the 2-band quad, the author checked it with a General Radio 1606 impedance bridge and found the 10-meter antenna to be about 118 ohms and the 15-meter antenna to be about 91 ohms at resonance. This is 2.36:1 and 1.82:1, or approximately 2:1 for a 50-ohm transmission line. The feed system described here made the VSWR much nearer the desired 1:1.

The heart of the system is a ferrite-core autotransformer. The measured impedance ratio is very close to 50:107 ohms. The insertion loss is less than 0.2 dB from 15 to 30 MHz when terminated in 107 ohms. When it is terminated in 50 or 200 ohms the insertion loss is less than 0.35 dB from 15 to 30 MHz. Several transformers were built before these figures were obtained, and after a suitable design was achieved it was connected to the quad as shown in Fig. 31. You do not have to sacrifice F/B ratio for a more acceptable VSWR by detuning the reflector stubs; simply adjust the tuning stubs for maximum F/B ratio and then design the transformer for the proper impedance ratio. Also, lowering the VSWR places a larger portion of the desired band within an impedance range the average pi-section tuner will accept.

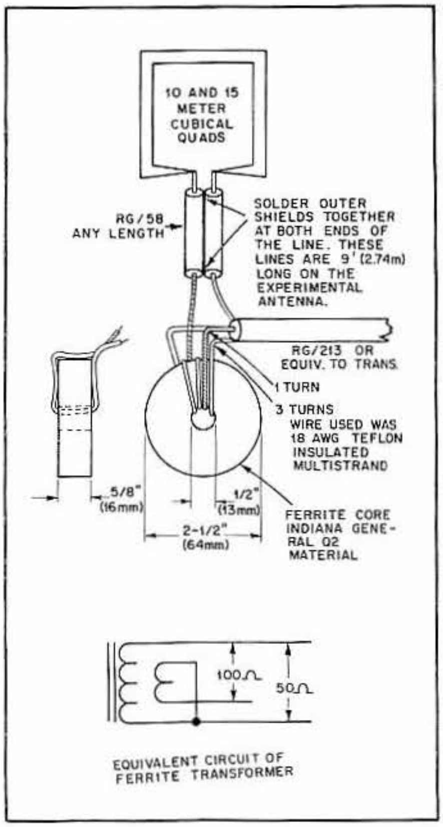

10 AND 15 METER CUBICAL QUADS
RG/58 ANY LENGTH
SOLDER OUTER SHIELDS TOGETHER AT BOTH ENDS OF THE LINE. THESE LINES ARE 9' (2.74m) LONG ON THE EXPERIMENTAL ANTENNA.
RG/213 OR EQUIV. TO TRANS.
1 TURN
3 TURNS
WIRE USED WAS 18 AWG TEFLON INSULATED MULTISTRAND
5/8" (16mm)
1/2" (13mm)
2-1/2" (64mm)
FERRITE CORE INDIANA GENERAL Q2 MATERIAL
100Ω
50Ω
EQUIVALENT CIRCUIT OF FERRITE TRANSFORMER

Fig. 31 — Two-band quad matching.

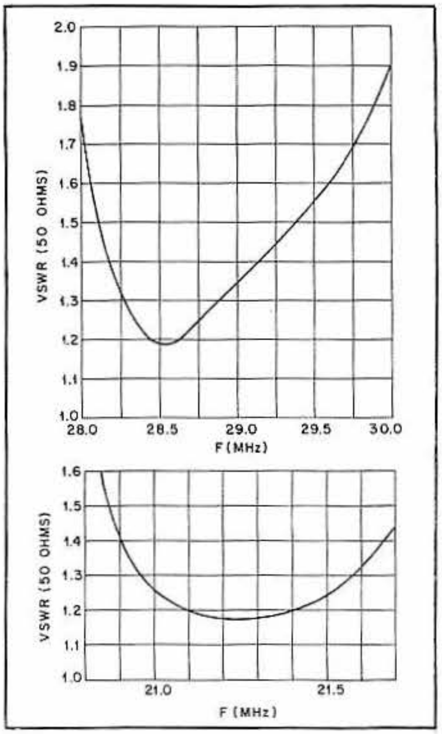


Fig. 32 — Standing-wave ratio curves taken with a laboratory-type VSWR bridge. Measurements were made at the transmitter ends of the transmission line with the antenna array mounted on a steel tower 44 feet (13.4 m) above ground.

In answer to on-the-air inquiries: Yes, performance of the antenna varies considerably from one end of the band to the other.

This antenna feed system is a broadband device, so don't forget to use a low-pass filter. This material was originally presented in *QST* by Toney L. Magnino, W5MVK.

Chapter 4

Miscellaneous Antenna Types

Here is a potpourri of useful antennas for the hf-band enthusiast. This chapter contains information on how to build and operate loop antennas, limited-space antennas and variations of the quad. Once again, the work of numerous *QST* authors has been collected for a timeless volume of useful construction details that can benefit amateurs whose operating objectives are numerous and varied.

For the most part, the antennas described in this section are simple and inexpensive to build. The performance characteristics are consistent with the operating needs of ragchewers, contesters and DX-chasers alike, assuming that the builder does not strive to have the loudest signal on the amateur bands.

Beat the Noise with a "Scoop Loop"

Operators on 160 and 80 meters fight a common foe — noise. Atmospheric QRN is compounded by the presence of man-made noise. Loop antennas for receiving may offer an economical solution to your noise problems. Here are some timely details.

If you've been tempted to massage your receiver with a 10-pound hammer because you can't copy some of the weak signals being heard by your colleagues, you may need a receiving loop! A high ambient noise level on 160 meters has stifled the author's DX work for several years, and more than once was ready to capitulate in favor of the man-made and atmospheric noises that the 75-foot (22.9-m) shunt-fed vertical responded to. "Grrrr," would be the snarl as the author listened to stations with Beverage antennas: They were handing out RST 579 signal reports to DX stations, and the author couldn't find the DX signals in the noise, let alone copy them.

Something had to be done. It was a matter of giving up on 1.8-MHz efforts toward DXCC, or putting forth a zealous attempt toward an improved signal-to-noise ratio. Some effective outdoor receiving antennas were erected (half-wavelength open loop — parallel to the ground, and a 200-foot [61-m] end-fed wire a few feet off the ground), but they did not always respond well to DX signals: It depended on band conditions. Also, there was the danger of receiver front-end damage caused by unwanted excitation of the large receiving antennas (resonant) during the transmit period. They were in close proximity to the vertical antenna, which was used for transmitting purposes. Lethargy prevented the author from installing a protective circuit at the receiver front end, and as a consequence the writer "blew" a JFET preamp and two protective diodes in the front end of the FT-301D transceiver.

Revisiting the Past

While for many years experimenting with small receiving loops for 40, 80 and 160 meters, the efforts were casual. The best of the loops was an outdoor one of the shielded variety, five feet (1.52 m) on a side, and fashioned from RG-59/U coaxial cable.[1] However, it was necessary to go out-of-doors each time to rotate it, and the author wasn't enthusiastic about investing in a rotator to use with the loop.

Recently, it seemed that some work could be done with indoor types of receiving loops. After all, loops of that kind have been around since radio was invented, and plenty of amateurs are using them effectively. After scanning available literature (Terman, Kraus, Jasik and Keen),[2] the author set about the task of building a framework for the chosen design. This time a multiturn loop would be tested (Fig. 1).

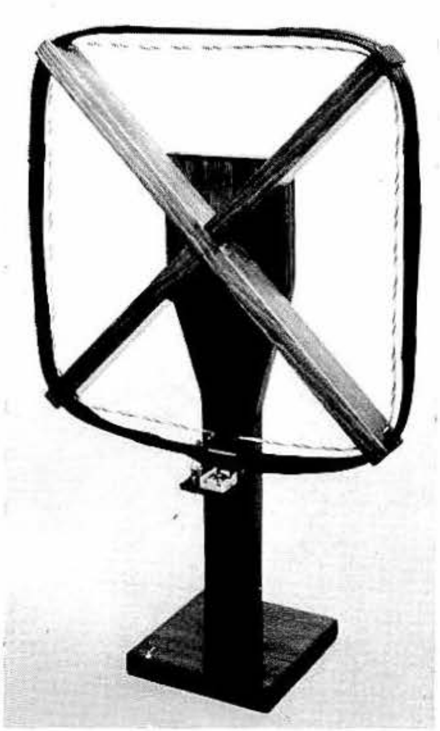
Construction

The photograph shows the general structure of the loop. In Fig. 2 are the dimensions of the wooden frame used to contain the antenna wires. There is nothing magic about the size of the antenna: Two pieces of wood that were stored in the workshop were used, each being 48 inches long, 1-1/2 inches wide and 3/8 inch thick (1.22 m × 38 mm × 10 mm).

Arbitrarily, the author decided to make L1 of Fig. 1 a five-turn winding. Holes were drilled (five) in each end of the cross-frame to accommodate the loop turns and hold them in place. Actually, there should be six holes at the bottom point of the frame to permit the final end of L1 to be secured during the threading-through process.

Five additional holes were drilled (Fig. 2) 3/4 inch (19 mm) below the holes for L1. These are used to contain L2, the one-turn output link of the antenna. L2 requires two holes at the bottom member of the frame — again to provide an anchor point for the ends of L2. Alternatively, V-shaped notches can be filed on the ends of the cross-frame. The wire for L1 can be laid in the grooves rather than threaded through the holes shown in Fig. 2. L2 should, however, be wound inside L1, through the five holes shown in the drawing.

A mounting base for the assembled antenna can be made to the builder's specifications. This writer used a piece of 3/4-inch (19 mm) plywood which has dimensions of 30 × 12 inches (0.76 m × 305 mm). A 1-inch (25 mm) diameter hole was drilled in the center of the board to accept an 18-inch (457 mm) length of 1-inch diameter dowel rod. The latter is lashed to the framework of the loop to enable the



The silhouette is of an indoor version of the four-turn shielded loop described in this article. A wooden framework is used to support the main loop winding and the one-turn pickup link. The resonating capacitor is mounted on an aluminum L bracket along with a phono jack and an 860-pF disk capacitor. The latter is used between the output link and the phono jack instead of a trimmer capacitor. The framework was built by Technical Secretary Marian Anderson's OM, Bob. It has been stained and coated with clear lacquer.

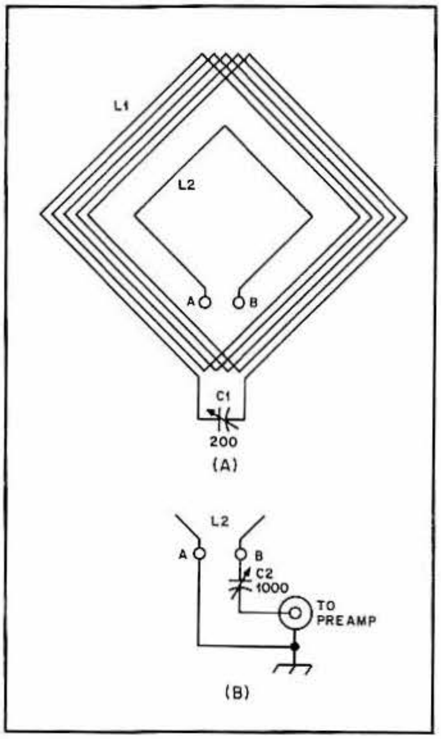


Fig. 1 — Schematic diagram of the receiving loop. C1 and C2 are mica compression trimmers. The illustration at A shows the 1-turn link inside the 5-turn one. At B is an expanded diagram of the feed point for L2.

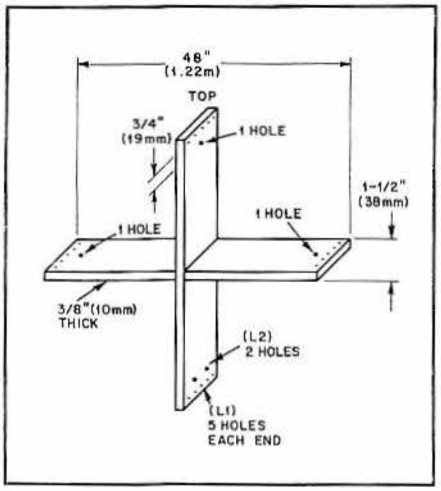


Fig. 2 — Dimensional drawing of the wooden frame which contains the Scoop Loop. Further information concerning the structure is given in the text.

operator to rotate the loop as desired. Although this is a "kluge" type of assembly, it serves its purpose adequately. A *carpenter* should be able to conceive a more practical base and support system for the antenna!

Number 22 insulated hookup wire was used for the loop turns. There is nothing critical about the wire size, but it is best to use the larger gauges. This will make the loop more rugged.

Performance

A variety of feed systems were tried before the author settled for the method illustrated in Fig. 1. Direct connection to the terminals of L1 required careful balancing to assure a uniform loop-response pattern. Unbalance causes pattern distortion, and if it's bad enough the maximum response can occur off the broad side of the loop rather than in the plane of the antenna.

Addition of a one-turn coupling loop, L2, proved to be the easiest method for assuring good balance. Bandwidth of the loop is dependent upon the Q. The latter can be controlled by the amount of capacitance used at C2: the lighter the coupling, the greater the loaded Q. Loop resonance is effected by means of C1. Since there is interaction between L1 and L2, it is necessary to readjust C1 each time C2 is tweaked. In this application it should be stressed that C2 is not used for the purpose of obtaining an SWR of 1. It is purely a *coupling* device. Hence, a 50-ohm condition does not necessarily exist at the loop output terminals.

During initial experiments the pickup loop, L2, was connected directly to the 50-ohm input port of a 40-dB broadband preamplifier which was designed by W7ZOI (Fig. 3). Without C2 in the circuit the coupling was excessive. This resulted in low Q, and the loop bandwidth was approximately 150 kHz at the 3-dB points of the response curve. After C2 was added and adjusted to provide a bandwidth of 25 kHz, the loop gain increased 10 dB. Alternatively, one might make L2 smaller and locate it closer to the center of the loop frame in order to lighten the coupling between the two windings. This could be a somewhat tedious mechanical procedure: The writer's inherent lassitude favored the addition of C2 for the purpose!

Performance Characteristics

A test range was set up for checking the null properties and relative gain of the loop. The equipment was arranged in an outdoor location, well away from power wiring and other station antennas. A crystal-controlled weak-signal source (2N2222A oscillator and 9-volt battery) was placed some 100 feet (30.48 m) from the test loop. It contained a 36-inch (0.91-m) whip antenna (vertically mounted) for radiation of the test signal. The 75-foot (22.86-m) transmitting vertical was shorted out at the feed point to prevent it from being resonant and affecting the loop antenna during the test period.

A 50-ohm Tektronix step attenuator was placed in the coaxial line between the loop and the receiver. The attenuator was used to measure accurately the changes in S-meter reading on the FT-301D transceiver which was used as a detector during the measurements.

A null depth of —21 dB was obtained with the loop. An extremely sharp null was noted. As the broad side of the loop was moved toward the signal source, the null began slowly, then fell deeply to —21 dB over the final 10 degrees of rotation. No evidence of pattern distortion was observed. The null was dead off the broad side of the antenna, and maximum response was directly off the thin side of the loop.

A comparison between the 75-foot (22.86-m) transmitting vertical (shunt-fed tower, top loaded and with buried radials) and the wire loop indicated that on groundwave signals the loop (without preamp in line) was —18 dB respective to the vertical. This suggested that in a practical installation a single JFET or dual-gate MOSFET preamp would provide unity gain with the transmitting vertical.

Using the Loop Indoors

The author's home has aluminum siding, and as is the case with all modern homes there is a network of water pipes, phone wires, TV lead-in conductors and house wiring. The author wondered how well the loop would perform within all of these unwanted signal obstacles, some of which form loops by themselves! The ham shack is at ground level inside the family room, and the loop was placed on a stand at floor level. The clutter of unwanted conductors disturbed the directivity of the loop somewhat, but the signal-pickup ability of the antenna was not impaired.

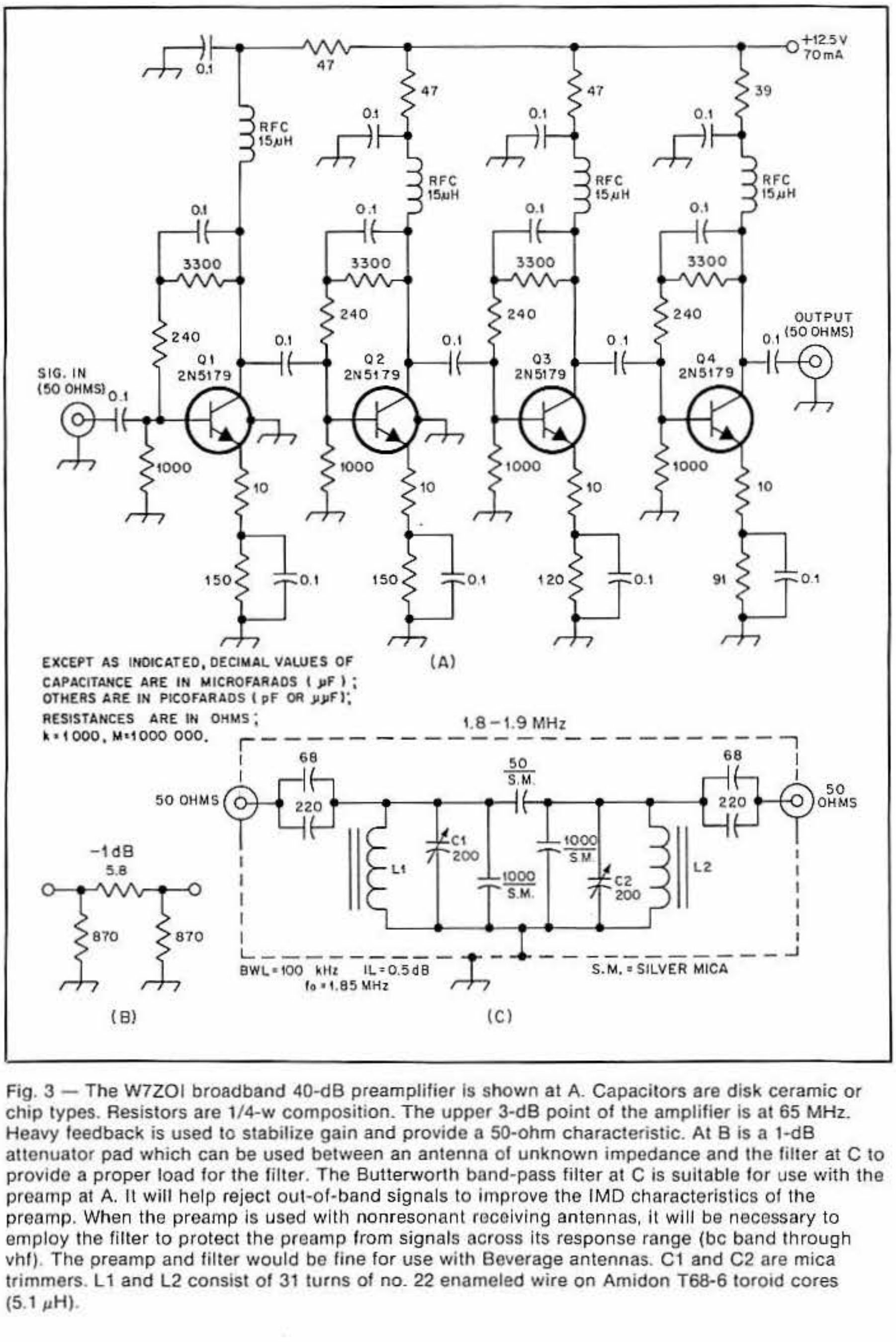


Fig. 3 — The W7ZOI broadband 40-dB preamplifier is shown at A. Capacitors are disk ceramic or chip types. Resistors are 1/4-w composition. The upper 3-dB point of the amplifier is at 65 MHz. Heavy feedback is used to stabilize gain and provide a 50-ohm characteristic. At B is a 1-dB attenuator pad which can be used between an antenna of unknown impedance and the filter at C to provide a proper load for the filter. The Butterworth band-pass filter at C is suitable for use with the preamp at A. It will help reject out-of-band signals to improve the IMD characteristics of the preamp. When the preamp is used with nonresonant receiving antennas, it will be necessary to employ the filter to protect the preamp from signals across its response range (bc band through vhf). The preamp and filter would be fine for use with Beverage antennas. C1 and C2 are mica trimmers. L1 and L2 consist of 31 turns of no. 22 enameled wire on Amidon T68-6 toroid cores (5.1 µH).

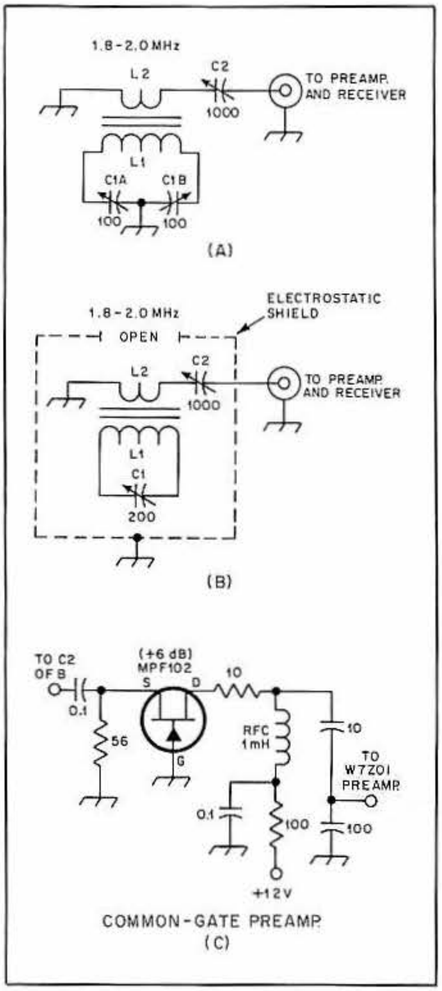


Fig. 4 — The drawing at A shows the circuit of a 7 X 5/8-inch (178 X 16-mm) ferrite-rod loop (see text). At B is the final version which employs an electrostatic shield. C1 and C2 are mica compression trimmers (see text for other details). The circuit at C was used ahead of the W7ZOI preamplifier to improve the system noise figure.

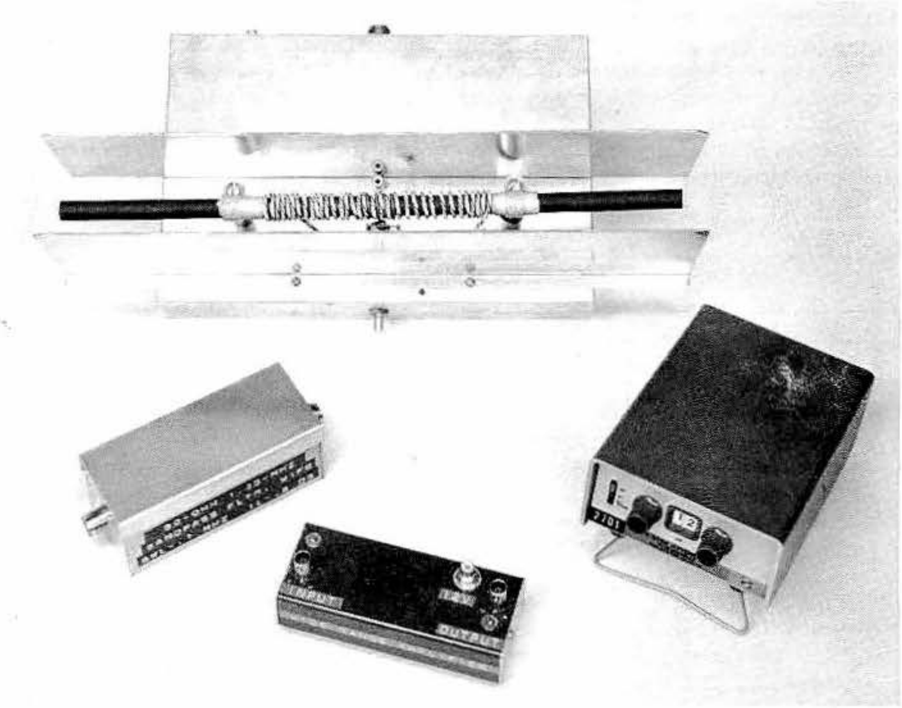
A step attenuator was inserted between the W7ZOI preamplifier and the station receiver so that unity gain could be established between the loop and the 160-meter vertical (22 dB of gain had to be gotten rid of). An antenna switch was added to the system to permit rapid comparisons between the antennas.

Extensive tests proved that the loop outperforms the vertical by a substantial margin when it comes to digging weak signals out of the noise (man-made and atmospheric). The author has copied PA0HIP, PY0ZAE, G3MYI, W6RW, W6BLZ, W5AB and others perfectly Q5 on the loop (indoors) when they couldn't be found, or were unreadable on the vertical. It is only fair to say that on some occasions the vertical was the better antenna for receiving. Propagation conditions and ambient noise levels at a given time will determine which antenna can provide the best reception. Typically, the ambient noise level from the W1FB vertical is S3 on a receiver that is calibrated to indicate S9 on a 50-µV signal.[3] The same receiver shows no noise response when the loop is connected to it. However, static crashes (atmospheric noise peaks) are as loud with the loop as they are with the vertical when a storm is in the immediate area. Noise from distant storms can be discriminated against by turning the loop null toward the storm front. It appears that the major part of the author's ambient noise is man-made in nature. At times it peaks as high as S8.

When the loop is used indoors it responsds to unwanted 15.750-kHz TV spurs, and when appliances are actuated the transients kick the receiver S meter rather hard. This is because the loop is contained within loops formed by house wiring. This type of interference has not been observed while using the vertical antenna, even though it is affixed to the rear of my house. To prove that the house wiring was causing the problem with TV birdies and transients, the loop was located out-of-doors for two nights. The interference vanished!

Some Other Loop Experiments

Ferrite-rod loops have been used to advantage for many years (bc-band radios, direction-finder receivers for boats and aircraft, etc.), so it seemed worthwhile to investigate a model of that type of antenna before concluding the tests. Two versions were tried, each with a preamplifier.[4] The first consisted of a single 7 × 5/8-inch (178 × 16 mm) Amidon Assoc. ferrite rod on which was wound a 40-turn solenoidal coil of no. 22 insulated hookup wire. The loop was tuned to resonance by means of a 100-pF per section split-stator variable. A four-turn output link was wound over the center



View of the ferrite-rod loop and test setup accessories. In the foreground (left) is the Butterworth band-pass filter. Below it at the center is the broadband preamplifier, and the Tektronix 2701 step attenuator is at the far right.

of the primary winding. The latter occupied approximately 3 inches (76 mm) of the center portion of the rod. A small aluminum chassis served as the foundation for the antenna, and the rod was spaced some 3 inches (76 mm) above the chassis. Performance tests showed the antenna to be less efficient than the large 5-turn wire loop. As referenced to the 75-foot (22.86-m) vertical, the ferrite loop was —38 dB. Furthermore, it was prone to the same induction effects which plagued the wire loop when both were used indoors. The rod-loop null was dismal — some 10 dB!

An improved model of the loop was built by using epoxy cement to join together a pair of 7-inch (178-mm) ferrite rods, end to end. The sensitivity (μV per meter) increases with the length of the rod, but is dependent upon the length of the coil which is wound on the rod. A multilayer coil contained at the center of the rod should be considerably better than a solenoidal coil spread over the major portion of the rod: The shorter the coil, the higher the Q of the antenna.

The author did not have Litz wire available, and was unable to build a multilayer coil, so a short solenoidal winding was placed on the center 5 inches (127 mm) of the 14 × 5/8-inch (356 × 16 mm) rod. It consisted of 32 turns of no. 12 insulated wire, spaced one wire diameter between each turn. The ferrite rods are made of Q2 material (μ = 125).

Fig. 4 shows the schematic diagram of the rod loop. A four-turn output link is wound over the center of L1. C1 is a mica compression trimmer which tunes the loop to resonance. C2 is used as a coupling capacitor to control the loop loading.

It seemed worthwhile to try shielding the loop, so a pair of aluminum L brackets were bolted to the chassis as shown in the photograph. Each bracket is 16 × 3-3/4 inches (406 × 95mm). The shields are spaced 1 inch (25 mm) either side of the loop.

The top of the U-shaped channel must be left open to prevent the shield from acting as a shorted turn. Proof of the effect can be seen by shorting across the open end of the trough (over the center of the rod) with a screwdriver. The received signal will vanish! An electrostatic shield, when used with a loop antenna, should minimize induced fields from nearby conductors and precipitation static, thereby making the system better for indoor use.

Rod-Loop Tests

The same outdoor test setup was employed for checking the performance of the rod loop. The nulls occur off the ends of the rod, and maximum response is found off the broad sides of the rod. A null of —23 dB was obtained with the loop, but efficiency was less than that obtained with the 5-turn wire loop. When compared to the 75-foot (22.86-m) vertical a reading of —31 dB was obtained, 13 dB inferior to the wire loop. The noise figure of the W7ZOI broadband preamplifier was too high for use with the new antenna, so a common-gate JFET pre-preamplifier was added between the loop output and the input to the 'ZOI unit. Ideally, a 30- or 35-dB preamplifier (two JFETs) should be used with the rod loop to assure a low noise figure and ample gain.

With the coupling set for maximum loop gain, the bandwidth (measured with an HP spectrum analyzer) is 10 kHz at the 3-dB points. The loop was measured independent of the shields and preamp for unloaded

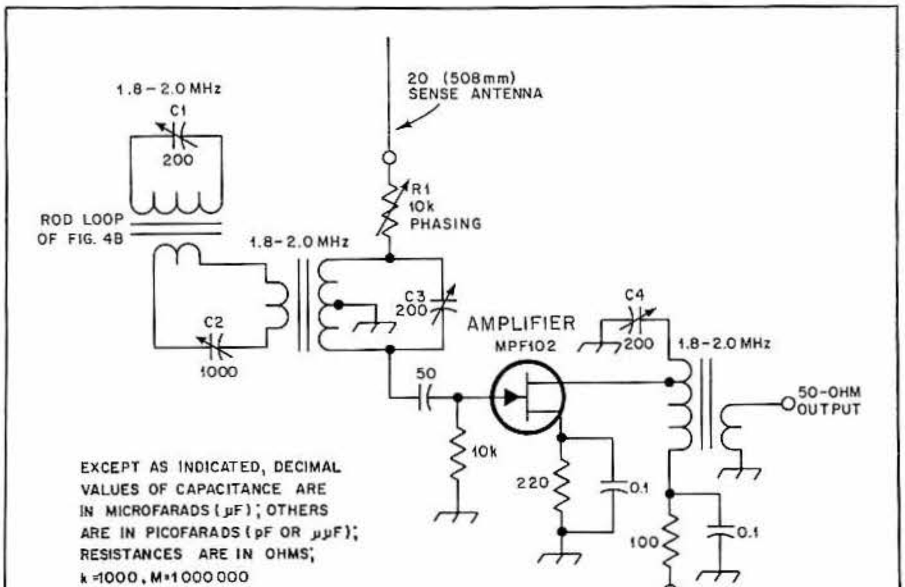
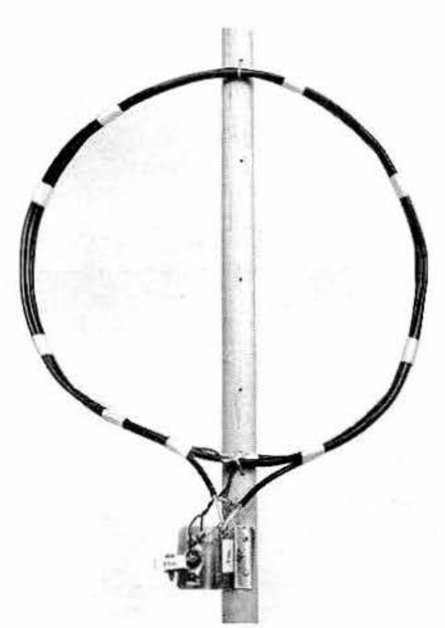

1.8-2.0 MHz
C1
200
ROD LOOP OF FIG. 4B
1.8-2.0 MHz
C2
1000
20 (508mm) SENSE ANTENNA
R1 10k PHASING
C3 200
AMPLIFIER
MPF102
C4
200
1.8-2.0 MHz
50
50-OHM OUTPUT
10k
220
0.1
100
0.1
+12V
EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF); OTHERS ARE IN PICOFARADS (pF OR $\mu\mu$F); RESISTANCES ARE IN OHMS; k=1000, M=1 000 000

Fig. 5 — Suggested circuit for using a sense antenna with the rod loop. The sense antenna can be mounted 6 to 10 inches (152 to 254 mm) in front of the broadside of the rod loop (centered). C1, C2, C3 and R1 are adjusted alternately for the deepest null possible off the rejection side of the loop (side opposite the sense antenna). It may be necessary to experiment with the length of the sense antenna to obtain the best null in the cardioid response pattern. The tuned circuits for the JFET preamp can be wound on T-68-2 toroid cores.

Q by means of an HP Q meter. A reading of 430 was obtained.

The electrostatic shield cured the unwanted pickup of TV spurs and appliance transients during indoor use. The author would like to mention that the wire and rod loops are affected to some extent by the presence of the 75-foot (22.86-m) vertical. The latter is only 20 feet (6.10 m) away from the operating position. It tends to reradiate noise and signals. Some of that energy is picked up by the loop antennas. If an indoor loop is to be used regularly, or if it is outdoors, but within 100 feet (30.48 m) or so of the vertical, the latter should be shorted out or detuned during the receive period. An spst relay could be slaved to the regular antenna change-over relay to accomplish this.

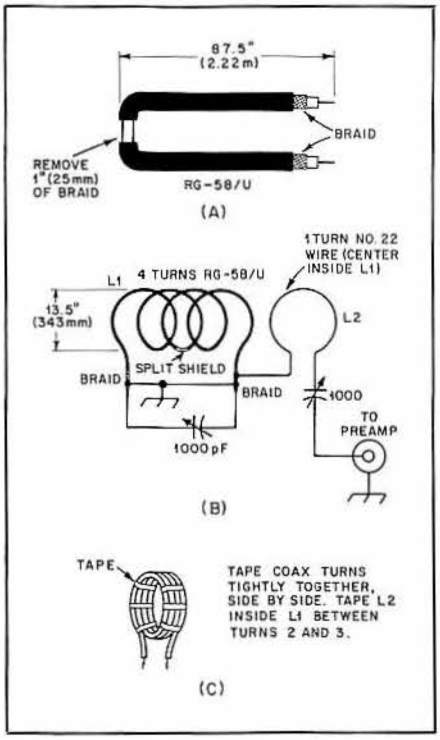


The 4-turn coax loop with electrostatic shielding. The trimmers are visible on aluminum brackets below the loop.

An improvement in performance for either type of loop could be had by adding a sense antenna and appropriate phasing circuit (Fig. 5). This would provide a cardioid pattern and result in a unidirectional response. Greater reduction of QRN and QRM would be effected through that technique. A weatherproof system of that type could be placed out-of-doors for year-round use. A TV type of rotator would be useful for changing the loop position, as desired.

The W1FB 4T-ES Loop

During a final investigation of loop types and performance characteristics, an attempt was made to devise a shielded loop small enough to be practical indoors. The primary objective was to develop a loop from ordinary materials — something that was inexpensive and easy to build. It should have efficiency comparable to that of the 5-turn wire loop described earlier in this report. A reasonable null depth and an undistorted pattern were sought also. From these criteria evolved the 4T-ES (four turn, electrostatic shield) loop shown in Fig. 6.



87.5"
(2.22 m)
BRAID
REMOVE 1" (25 mm) OF BRAID
RG-58/U
(A)
1 TURN NO. 22 WIRE (CENTER INSIDE L1)
L1
4 TURNS RG-58/U
13.5" (343 mm)
L2
SPLIT SHIELD
BRAID
BRAID
1000
TO PREAMP
1000 pF
(B)
TAPE
TAPE COAX TURNS TIGHTLY TOGETHER, SIDE BY SIDE. TAPE L2 INSIDE L1 BETWEEN TURNS 2 AND 3.
(C)

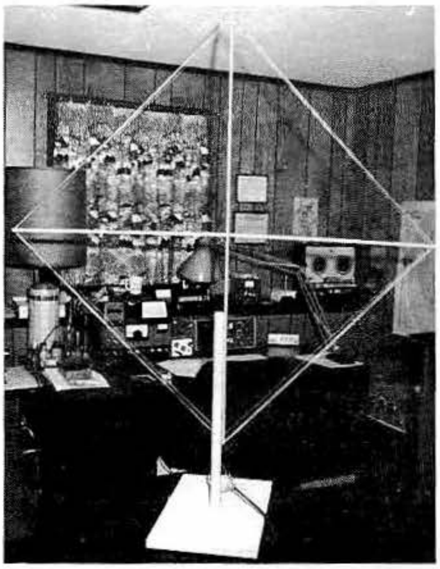
Fig. 6 — Structural details of the W1FB 4T-ES loop antenna. At A is an illustration of the total length of RG-58/U before the loop is formed. An expanded view of the loop turns and pickup link is given at B. Drawing C shows how the loop turns are taped together side by side as the antenna takes its final form.

It consists of four turns of RG-58/U cable which are formed into a circular configuration to provide a diameter of 13-1/2 inches (343 mm). There is nothing critical about the diameter, and RG-59/U coaxial cable could be used instead of the type specified. The turns are formed side by side, then taped at several points to maintain the loop form.

It is necessary to split the shield braid at the electrical midpoint of the loop. This prevents the shield from acting as a shorted turn. The principle is the same as that described for the ferrite-rod loop with its aluminum-channel shield. The braids are joined at the loop feed point and made common to one end of L2. The three grounded elements are then attached to the coaxial connector ground terminal on the loop support frame.

Loop performance was checked by using the test procedure discussed earlier. A null depth of —26 dB resulted. There was no discernible pattern warping, and the null occurred deeply over just a few degrees of rotation. The 4T-ES was 18 dB inferior to the 75-foot (22.86-m) vertical antenna when checking distant signals. The unloaded Q was measured by means of the HP Q meter. A value of 85 was obtained. Because C2 was set for light loading of the loop, a bandwidth (3-dB points) of 20 kHz was obtained when the preamplifier and receiver were connected to the antenna.

Numerous comparisons were made on DX signals from Europe and the Caribbean area during the ARRL DX Contest in March of 1977. In all instances the 4T-ES was as good as or better than the 75-foot (22.86-m) vertical. Ambient noise was considerably lower in amplitude while using the loop, even though all tests were performed with the loop indoors at ground level. There was no reduction in atmospheric noise (which was high that weekend) because the maxima of the loop favored the N.E. and S.W. directions: The storm front was S.W. of Connecticut. However, rotation of the loop caused a drop of 26 dB in the static crashes when the loop nulls were S.W. and N.E. Because of the electrostatic shielding there was minimum noise induction from the house wiring — a contrast to the performance characteristics of the unshielded 5-turn wire loop. The W7ZOI broadband preamplifier and an attenuator were used during the tests. There were some instances when the loop provided a stronger signal response than the vertical, even though the two systems were adjusted for unity gain.



Close-up view of the 160-meter indoor receiving loop at W1FB. The antenna is resting on a piano bench, and is situated near the operating position so that it can be hand-rotated as necessary.

The 4T-ES is suitable for use indoors,

but it could be weatherproofed for outside installations. Epoxy cement could be used to seal the open ends of the coaxial cable of L1, and the trimmer capacitors would survive the natural elements if housed in a metal or plastic container.

In Summary

The loops that have been discussed here should be suitable for use on 40 or 80 meters if scaled accordingly. They may not show much directivity on sky-wave signals because of the "tumbling effect" at the higher frequencies. But QRM from nearby amateurs could be reduced greatly, and man-made noise sources could be rejected significantly by correct orientation of the loop.

The author has attempted to discuss some of the characteristics of small loops which are not treated in most of the references contained in amateur journals. There is plenty of latitude remaining for experimentation, and the reader is encouraged to apply his or her skills in developing better loops for amateur use. Meanwhile, why not build a small loop and scoop those weak signals out of the noise? It could mean some new countries for you on "top band" or 80 meters. This material was originally presented in *QST* by Doug DeMaw, W1FB.

References

[1]DeMaw, "A Receiving Loop for 160 Meters," *QST*, March 1974.

[2]Terman, *Electronic & Radio Engineering*, McGraw-Hill. Kraus, *Antennas*, McGraw-Hill. Jasik, *Antenna Engineering Handbook*, McGraw-Hill. Keen, *Wireless Direction Finding*, 3rd Edition, Iliffe & Sons, Ltd.

[3]DeMaw, "His Eminence — the Receiver," Parts I and 2, *QST*, June and July 1976. Receiver used in combination with an Autek Research QF-1 RC active audio filter.

[4]DeMaw, "Build This Quickie Preamp," *QST*, April 1977.

The Half Square Antenna

Do those 100 countries still elude you for 80-meter DXCC? In terms of dollars versus decibels, a half-square antenna may be your best bet for putting punch into your signal.

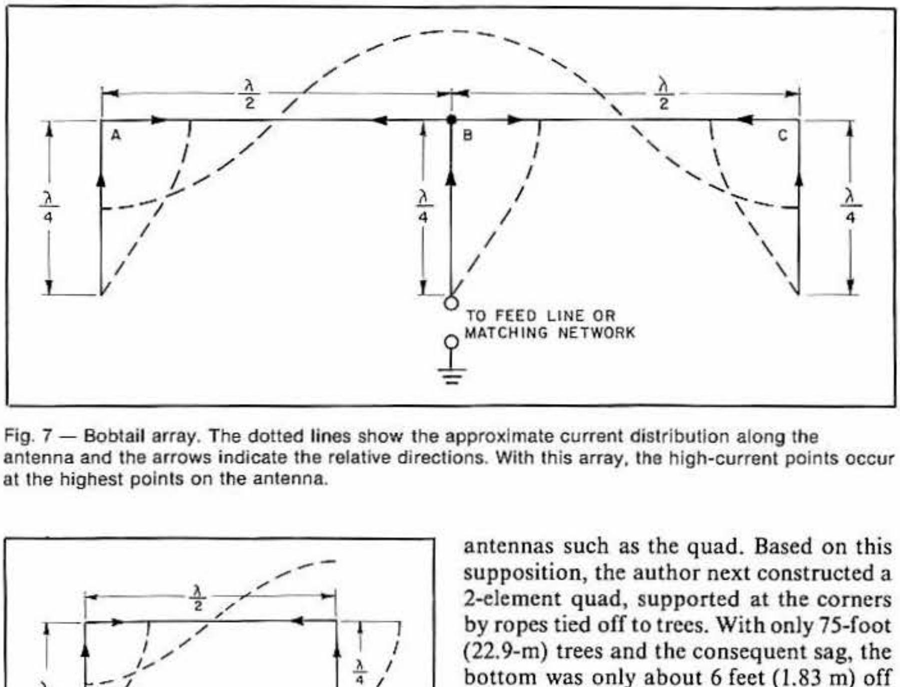


Fig. 7 — Bobtail array. The dotted lines show the approximate current distribution along the antenna and the arrows indicate the relative directions. With this array, the high-current points occur at the highest points on the antenna.

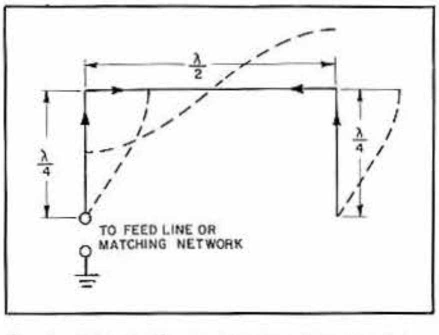


Fig. 8 — The "half-square" evolved when one leg broke off the bobtail. The input impedance of both the bobtail and half-square antenna is very high, which eliminates the need for an elaborate ground system at the feed point. Either a parallel-tuned circuit or a quarter-wave transformer can be used to match to a 50-ohm feed line.

With 5-band DXCC as bait, considerable interest has arisen in DX and antennas for the lower frequency ham bands. The author's attempts to get a decent 80-meter DX antenna have gone through an evolutionary cycle with a lot of iterative tries and with steadily improving results. The half-square antenna that is the latest of these has some interesting properties and gives about as many "dBs per buck" as any this author has seen.

Before describing this configuration, it might be interesting to cover briefly the different antennas tried which didn't work as well. The writer's available options were set up by (1) a yard full of tall trees and (2) very little money to spend. The first antenna was an inverted V hung on the 75-foot (22.9-m) tower. This is really a quite good antenna — primarily because it has the high current part of the antenna at the highest support point. It provided a standard against which all succeeding antennas were checked. The next step was to add a parasitic element (director) which didn't seem to help at all. This is perhaps not so surprising with the ground so close. Viewed simply, normal parasitic coupling is dependent upon a fair proportion of the current in the driven element being coupled to the parasitic element. When they are both close to the ground, the reverse polarity of the image of the driven element starts to couple heavily to both the driven element and the parasitic element, making it practically impossible to get the desired parasitic current at any useful spacings.

This effect has been shown experimentally to be less with closed-loop type antennas such as the quad. Based on this supposition, the author next constructed a 2-element quad, supported at the corners by ropes tied off to trees. With only 75-foot (22.9-m) trees and the consequent sag, the bottom was only about 6 feet (1.83 m) off the ground. However, the quad did work, had an acceptable feedpoint impedance, and gave a few dB (about 1/2 an S unit) improvement over the inverted V on European contacts. Obviously, the only useful low-angle radiation in this antenna came from the upper half of it, the lower half serving to feed or excite the upper half. A major problem with the quad was keeping it up. It had to be very tightly stretched between trees to keep it from sagging to the ground and as a result the wire often broke.

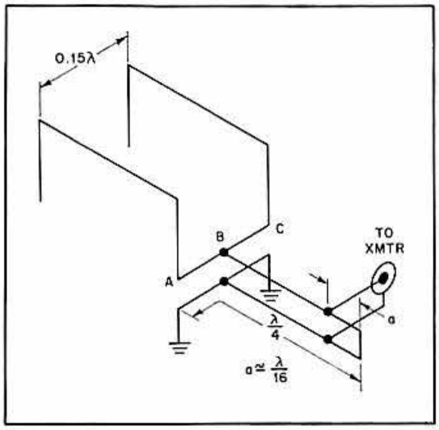


Fig. 9 — Two-element half square array gives greater gain and a very wide bandwidth.

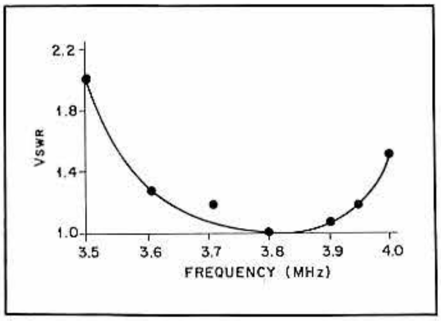


Fig. 10 — Measured SWR of the antenna shown in Fig. 9.

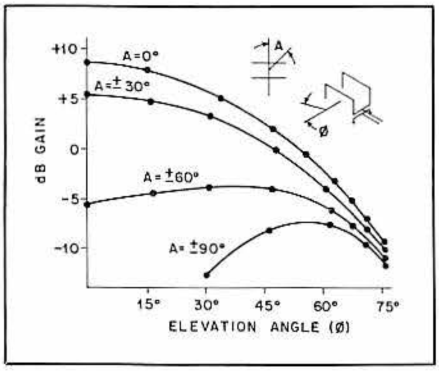


Fig. 11 — Computer-pattern plot for a 2-element half square array with 0.15-wavelength spacing between elements. The angles referred to in the drawing are shown in the inset.

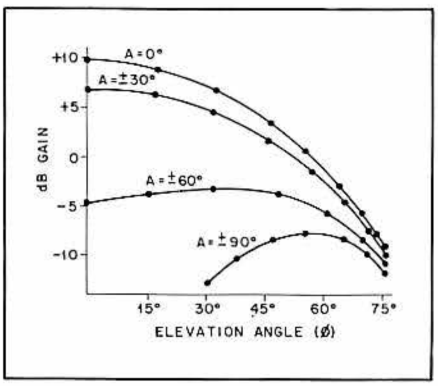


Fig. 12 — Computer-pattern plot for the antenna of Fig. 11 with 0.25-wavelength spacing.

To try another tack which would avoid the parasitic coupling problem an 8JK array with four half-wave elements was tried, all elements being fed. With the span of this being so long and with lots of high-voltage points which had to be kept from touching the trees, the author only managed to get it to a height of about 40 feet (12.19 m). The signal-report results with this were essentially identical to the quad on the path to Europe. The horizontal beamwidth was noticeably less than the quad. It probably would have done better if the writer could have gotten it to 75 or 80 feet (22.86 or 24.38 m) in height.

The next antenna tried was the so-called bobtail which is shown in Fig. 7. This is a broadside vertical array with approximately twice the current in the center leg as the two outer legs and with current distribution in the horizontal wires which tend to cancel horizontally polarized emission.[1] A major reason for trying this was the author's frustration with trying to use the maximum available height of the trees and still be able to feed the antenna and keep the high-voltage points clear of the tree branches. The author had avoided vertical antennas before because of the difficulty in getting a good low-loss ground. Also, the trees looked like great vertically polarized rf energy eaters. The bobtail is particularly nice for tree hanging since its highest support points (A, B, and C in Fig. 7) are all at low impedance and looked as if they could be directly slung over a tree limb with no insulators. It is fed from the bottom at a high-impedance point so the ground system doesn't need to be as good as it does with low-impedance feedpoints. Also, like the inverted V, the bobtail has its maximum current at the highest support point. It can be excited from a parallel-resonant tank circuit or a quarter-wavelength stub.

The bobtail has been an outstanding performer. It's at least an S unit better than the inverted V and works great on DX paths to the Far East (JA, KG6, and VS6). The author put up two of these at right angles and found their interaction to be practically nil even though their center legs are quite close. When switching, the author ground the feed point of the one not in use.

The Half-Square Antenna

With such fine results, it was thought the ultimate "tree-hung" antenna had been discovered. However, after a particularly bad storm, it was noticed that one leg of the bobtail had broken off and yet the antenna feed impedance hadn't changed noticeably. Furthermore, the results compared with the inverted V seemed about the same as the full bobtail. Fig. 8 shows the configuration. It is a 2-element (instead of 3) vertical broadside array with the same current in both legs. It has all the advantages of the bobtail except that the radiation from the horizontal part of the antenna doesn't cancel as well in all directions and some end-fire, horizontally polarized energy does spill off. This might be considered an advantage or a disadvantage, depending on whether you're seeking coverage or discrimination! In discussing this with Ed Watters, WA3LGX, he pointed out the kinship this antenna has with the bisquare array. It's sort of half of a bisquare laid sideways with the ground image antenna making up the other half. That, plus its obvious shape, led the author to dub it the half-square antenna.

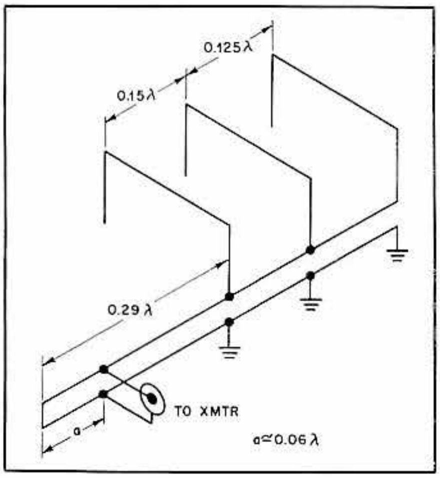


Fig. 13 — A 3-element half-square array.

After using a single half-square for awhile, it was decided to add another element with about 0.15-wavelength spacing. With the new element in place, a check was made to see what parasitic coupling there might be between elements. With several hundred watts fed into the driven element there was no evidence of rf on the parasitic element (using a neon bulb). This was a very gross measurement which tended to confirm what was expected. The very close proximity of the antenna to ground tends to reduce greatly parasitic coupling to a nearby element. Being puzzled why it should appear so small, the only hope was to devise a means of measuring this coupling more accurately.

Having had to tear down the 8JK antenna to get enough wire for this antenna, as a first try for feeding it, the author just used the 8JK open-wire line and stub match as it existed. The one wavelength of wire for each element was taken directly from the 8JK also. Fig. 9 shows the configuration. Unlike the 8JK, which was narrowband (centered around the middle of the band), this configuration gave the very flat SWR shown in Fig. 10 — on the first try! The SWR was not very different whether the feed-line stub was connected to point A, B, or C (Fig. 9). B gives a bidirectional characteristic while connection to A or C gives some unidirectivity. The author is still suspicious of the wide bandwidth and suspects the two elements may be different effective lengths, giving a stagger-tuned effect. If the spacing between these two were increased to a quarter wave and fed at point A or point C, it should theoretically add another couple of dB gain

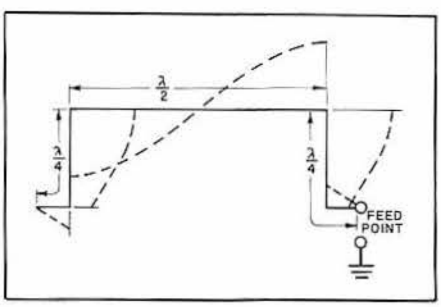


Fig. 14 — Any of the antennas mentioned can be bent as shown in order to keep the current loops at the upper corners.

and give a more significant front-to-back ratio than with the 0.15-wavelength spacing. WA3LGX plugged the dimensions and shape of this antenna into a generalized computer program he has developed for wire antennas and got the curves shown in Figs. 11 and 12. Fig. 11 defines the forward pattern for 0.15-wavelength spacing assuming a perfectly conducting earth. Fig. 12 is for quarter-wave spacing. The actual patterns will be modified at angles below 10° to 15° by the earth's resistivity[2] as is the case with any vertical antenna. The 0.15-wavelength-spaced antenna was used for some time and consistently gave better results than the bobtail on the path to Europe.

The writer took one other step beyond the 2-element array and added another element at 1/8-wavelength spacing (see Fig. 13). The extra element is fed, as are the other two, with an extension of the same open wire line. This antenna is considerably quieter (less QRN) than any of the other 80-meter antennas the writer had and has better than half an S unit advantage over the bobtail on European signals. It doesn't require any retuning to cover the whole band.

With these antennas not insulated at their support points, one might expect some effects when the tree sap rises or in wet conditions. The author hasn't been able to notice any differences from dry weather to monsoon-type rains or wet snow covering everything. The trees are slightly over 1/4-wavelength high on 80 meters. Considered as antennas or absorbers, they would look like grounded 1/4-wavelength vertical radiators. The vertical sections of the half-square antenna that run close to the trees are just the opposite. That is, at the bottom of the antenna the voltage is high and at the top, the voltage is low. This should minimize coupling to the trees, as opposed to, for example, using 1/4-wavelength grounded verticals for the antenna elements.

160-Meter Operation

Now if you look closely, you can see that the 80-meter half-square whether 1, 2 or 3 elements, should make a good antenna for 160 meters. Each element is 1/2-wavelength long on 160 meters, voltage fed on the end, and the high current part of the antenna is at the maximum height. True, a higher impedance part of the antenna touches the tree, but you can't have everything free! While not having managed to work any DX with the few watts available on 160 meters, the author can *hear* Central European ham stations quite well on this band for the first time ever at this location. Of course, a different stub or tuning arrangement is necessary for getting a low SWR on 160 meters. The writer just unshorted the stub and put a tapped coil (about 14 microhenries) in series with the coax feed line to tune it.

Construction Details

These antennas were all built with no. 14 soft-drawn copper wire. The elements are pulled over the top limbs of trees that have approximately the correct spacing and tied to nylon strings at about shoulder level. If your trees aren't a full quarter wave high, the extra wire can be stretched out parallel to the ground at each end as shown in Fig. 14. Note that you still get the maximum current point at the highest support point you have.

The best technique found for getting a line over the highest tree is to use a fisherman's casting reel (I use a Zebco 202) with an 8-pound nylon line and a 1- or 1-1/2-ounce sinker. The reel is put in the RELEASE position and a sling shot is used to shoot the sinker and line over the desired tree. This is a very accurate technique and you can easily put a line over 90-foot (27.43-m) trees. The light fishing line is used to pull over a heavier line. It's a good idea to paint the sinker a bright color since the line is almost invisible. You can waste a lot of time looking for the sinker at the end of the line.

Be sure to leave enough droop in the horizontal section of the antenna to allow for tree motion in high winds. The open-wire feed line used for the harness and stub sections is made with the same no. 14 wire spaced 3-1/2 inches (89 mm).

The avid Field Day or camping fan will notice the obvious advantages of the half-square antenna for that type of operation. It uses minimum materials, goes up very quickly, will really put out a booming signal on 80 meters, and can be taken down in just a few minutes. You can also make good use of the fishing rod in between your turns at the key. This material was originally presented in *QST* by Ben Vester, K3BC.

References

[1] [Editor's Note: While complete cancellation of the horizontally polarized component occurs at a point broadside to the array, some radiation from the flat-top portion will exist at other angles. This is because of incomplete cancellation of the components from the opposite ends of the flat top.]

[2] *The ARRL Antenna Book*, 12th Edition, p. 46.

The HRH Delta-Loop Beam

Here's an antenna that should excite the interest of the amateur fraternity. The Delta-Loop beam has all the features of a quad without many of the disadvantages.

The evolution and design of the antenna shown in the photographs came about primarily because of a lack of confidence in the mechanical durability of quads. Anyone who has ever built and used quads knows how difficult it is to keep them up in icing and high wind conditions.

The author being an old-time mechanic, felt there had to be a better design for an antenna that used full-wave elements in a parasitic array, so some years ago a start was made to find that better design. One thing that nearly all readers will agree is that Mother Nature is about the best designer there is. Along these lines, just observe the growth of branches on tree limbs. You'll find that many of the smaller branches will grow up in a semivertical pattern from the limb; see Fig. 15. It takes a considerable amount of icing and wind to break such branches, indicating the soundness of the design. This same idea should apply to elements mounted on a boom.

To test the idea, an element of aluminum tubing was mounted on a boom. The element was mounted as shown in Fig. 17. The boom was then secured to the family car with the element in a vertical position. The assembly was then tested at 65- to 75-mph. Even though the element was only secured to the boom as shown in Fig. 17, there was no "set" or permanent bending. This test opened the door to several possibilities in beam design.

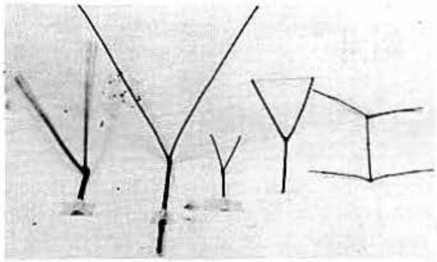
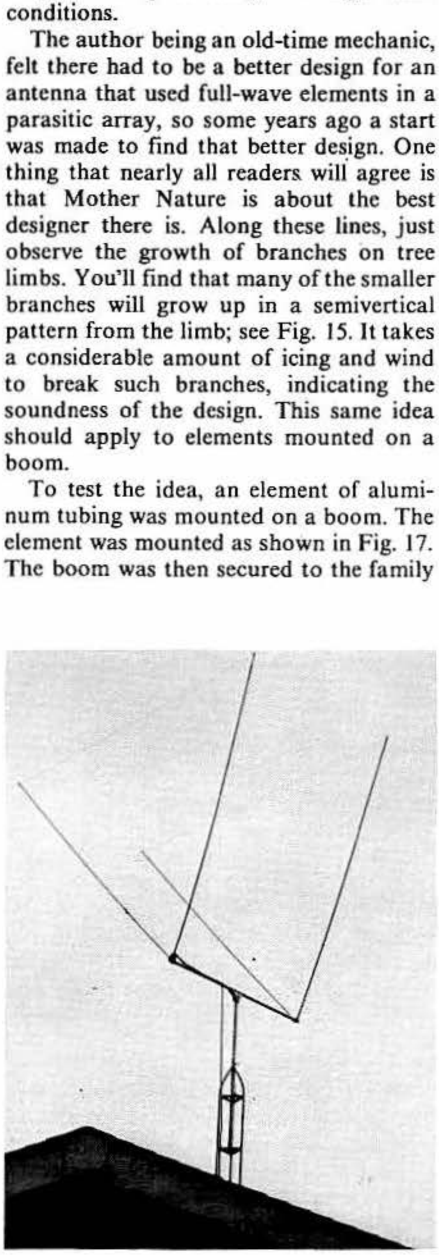


Fig. 15 — The basic idea for the Delta-Loop beam was conceived from the growth of tree limbs and branches. Here are just a few of nature's configurations that lend themselves to antenna design!



This is a 10-meter, 2-element Delta Loop that is very similar in construction to the antenna described in the article.

A loop aerial can take many shapes. Anyone who studies the history of the quad will find that many different configurations have been used. Why not use a triangle?[1] It should be possible to achieve a very good design using a vertical triangle. See Fig. 16. This shape appears ideal for a beam with full-wave elements, and has most of the advantages of the quad without many of the disadvantages. This led to the construction of several antennas of the type shown in the photographs, and some of these advantages become quickly apparent.

First, the entire antenna is *above* the boom. Second, the antenna is constructed primarily of aluminum tubing, which provides extra strength as compared with wire elements. Third, the antenna has Plumber's Delight type construction, meaning that the antenna is at ground potential for lightning protection, plus the fact that this type construction lends itself to gamma matching of the feed point, eliminating the need for a balun. Last, but not least, we find the antenna is very attractive in its symmetry. Of course, the important point is how well does the antenna perform?

Several 10-meter models have been tested and the unit shown in the roof-mounted position is 20-meter Delta Loop. Using a gamma match with 50-ohm coaxial feed, a 10-meter model was matched at 28.8 MHz. The antenna consisted of a driven element plus reflector with the elements spaced 6-1/2 feet (2 m) apart, or approximately 0.2 wavelength. Surprisingly, the antenna was extremely flat across the entire 10-meter band, the worst mismatch being *less* than 1.2 to 1.[2]

The author has no means of measuring gain or front-to-back ratios. However, with the spacing and element sizes the same as a quad, the gain should be the same, or at least so close the difference would be insignificant. On-the-air tests have shown the antenna to be as good as or better than quads the author has had up. Front-to-back and front-to-side reports have been outstanding, both on ground wave and skip.

Element Lengths

Many tests have been made on driven elements to determine the effect of element lengths on SWR. It was found that the flattest curve was obtained with the formula

$$\frac{1005}{f_{MHz}} \text{ (feet)}$$

for the driven element. The reflector should be about three percent longer, or

$$\frac{1030}{f_{MHz}}$$

If directors are desired it would appear that a length three percent shorter than the driven element would be adequate.

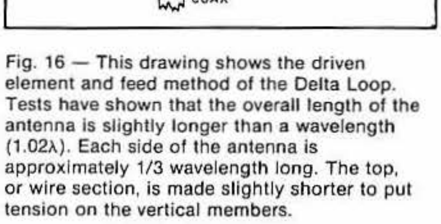


Fig. 16 — This drawing shows the driven element and feed method of the Delta Loop. Tests have shown that the overall length of the antenna is slightly longer than a wavelength (1.02λ). Each side of the antenna is approximately 1/3 wavelength long. The top, or wire section, is made slightly shorter to put tension on the vertical members.

Table 1

Bill of Materials

Tubing used is 6061 T6.

4 — 12-foot lengths of 3/4-inch OD, 0.035 wall (elements).

1 — 12-foot length 1-3/4-inch OD, 0.065 wall (boom).

8 — 3/4-inch diameter stainless steel hose clamps.

1 — 9-inch length of 3/8-inch OD by 5/16-inch ID.

1 — 9-inch length of 1/2-inch OD to slide over 3/8-inch section.

25 feet of copper wire no. 12 or 14, or equivalent in stranded wire.

Feet X 0.3048 = m.
Inches X 25.4 = mm.

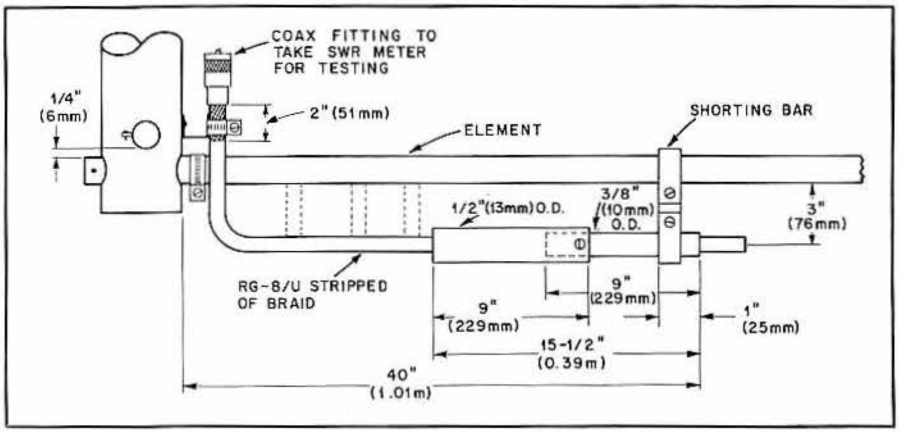


Fig. 18 — Here are the details on the gamma-matching section. As mentioned in the text, the coax fitting can be a female type SO-239, mounted on a small bracket which is mounted on the boom. Spacing insulators for spacing the gamma line from the element can be made up from pieces of Lucite or Plexiglas.

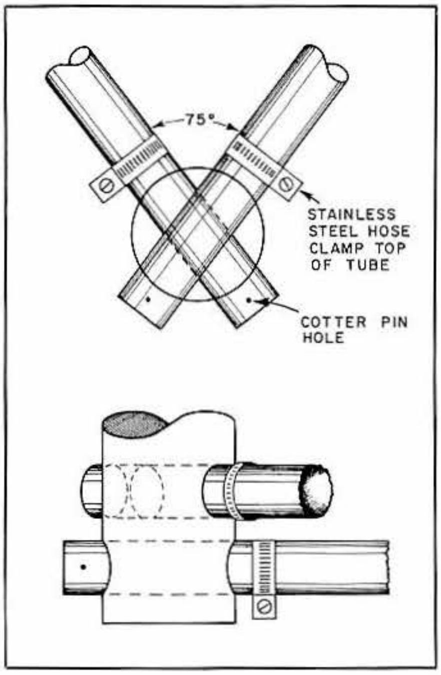
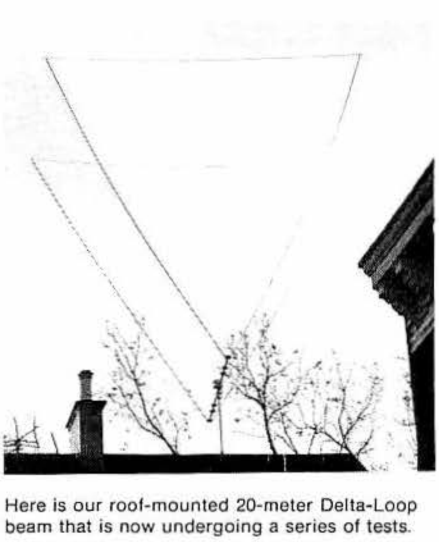


Fig. 17 — This drawing shows the method of mounting the element to the boom. A cotter pin is used on the under side of the boom and a hose clamp on the top to hold the element securely to the boom.



Here is our roof-mounted 20-meter Delta-Loop beam that is now undergoing a series of tests.

As to element spacing, the author has long been an advocate of wide spacing (0.17 to 0.2 wavelength) whenever possible. In the 10-meter tests 0.2 wavelength spacing was used.

For readers who are interested, complete construction information on a 10-meter model, including a list of the required tubing, follows.

Construction Notes

Fig. 17 shows the method of mounting the element tubing to the boom. The angle between the semi-vertical elements is shown as 75 degrees but this can vary a few degrees either way without any appreciable effect on the performance of the array. It is difficult to drill and line up the element support holes in the boom and come out to *exactly* 75 degrees.

There are a couple of methods of making the holes in the boom to hold the elements. One of the simplest is to use a Greenlee-type chassis punch. This makes a clean hole in the boom. Another method is to drill holes large enough to take the end of a 3/4-inch (19-mm) reamer and then ream out the holes to the necessary diameter.

One not accustomed to working with angles might find it difficult to drill holes at a 75-degree angle. A simple method is to first drill holes to take a single element. Next, make a jig from a piece of stiff cardboard or similiar material, using a protractor to get the 75-degree angle. Then insert the single element into the boom and lay the jig along the element; this will give you the correct alingment for the other element.

The elements are inserted through the boom just far enough to take a cotter pin on the underside of the boom. On the top side, a hose clamp is used to hold the element to the boom and prevent slippage. A length of copper wire can be wrapped around both elements just below the clamp to insure a good contact between the elements and the boom. Hose clamps are also used at the tops of the elements to hold the horizontal wire.

Fig. 18 shows the details of the gamma matching section. The gamma section is made up from the inner conductor of the coax, including its insulation, and two sections of telescoping aluminum tubing. The outer covering and braid is removed from a 52-inch (1.32-m) length of RG-8/U coax. In Fig. 18, a male coax fitting is shown with a short length of braid, 2 inches (51 mm) long, which is grounded to the boom via a clamp and bracket. If desired, a chassis-type coax fitting, type SO-239, could be mounted on the boom with a small metal bracket. The capacitor section is made of two lengths of tubing 3/8-inch (10 mm), and 1/2-inch (13 mm) diameter, respectively, and both 9 inches (229 mm) long. The 3/8-inch (10 mm) tubing fits over the insulation around the coax inner conductor while the 1/2-inch (13 mm) tubing slides over the 3/8-inch (10 mm) material. The larger tube is drilled and tapped to take a locking screw. Spacing of the section from the element is 3 inches (76 mm).

In adjusting the gamma, figures given in

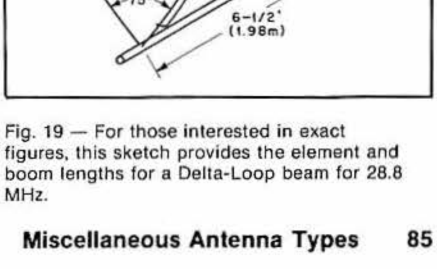


Fig. 19 — For those interested in exact figures, this sketch provides the element and boom lengths for a Delta-Loop beam for 28.8 MHz.

Fig. 19 can be used as a guide. In order to avoid matching errors, the gamma should be adjusted with the SWR bridge right at the beam. Set the shorting bar to the dimension given in the diagram and slide the 1/2-inch (13 mm) tubing over the smaller tubing, looking for a setting that gives a match. If one cannot be obtained, move the shorting bar and sliding tubing assembly a short distance, say an inch (25 mm), and then try different settings of the 1/2-inch (13 mm) tubing until you find a match. We found that the settings were not critical in getting a match. Once the beam is matched, the regular feed line to the station can be attached to the feed point. The connection should be taped to prevent moisture from getting into the fitting and coax.

As stated earlier, the antenna is extremely flat across the entire 10-meter band. The present model was designed for 28.8 MHz and matched at this frequency. The SWR at the highest point, at 29.7 MHz, was about 1.2 to 1. This dropped to 1 to 1 at about 29 MHz and stayed at 1 to 1 all the way down to 28 MHz. This feature of the antenna certainly is a help when using a transceiver designed for 50-ohm output. The beam has proved its ruggedness through winds and icing conditions. All in all, we think the Delta-Loop beam is one of the best performers we have seen. This material was originally presented in *QST* by Harry R. Habig, K8ANV.

References

[1] [Editor's Note: A triangular loop configuration also was described in *QST* in April 1968, "Technical Correspondence" by Norman Watson, W6DL, independently of K8ANV's design. Mr. Habig has been working for some years on this design and has a patent pending.]

[2] [Editor's Note: A 10-meter model of the Delta Loop beam tested at ARRL headquarters was matched at 28.8 MHz and an SWR curve was made using a Bird Wattmeter. The largest mismatch also was less than 1.2 to 1 MHz (at 29.7 MHz).]

The Delta-Loop Beam on 15

DX capability, low SWR and readily available construction materials are highlights of this 15-meter beam antenna. Similar to a quad, but rugged as a Yagi — those are the virtues of the Delta Loop.

Some of the features of the 15-meter beam described in this article include a very low SWR across the entire band, use of readily available materials, "Plumber's Delight" type construction — which is always an appealing feature of any beam antenna — and last but not least, excellent performance. On the last point, the antenna shown in the photographs was tested during a DX contest with a transmitter input power of 100 watts. The boom of the antenna was mounted only eight feet (2.44 m) above the ground, but in about five hours of contest operation 58 different countries were worked — and, believe it or not, the majority of the reports received were 59. Possibly conditions were above par, but even so the antenna shows it can do a real job under crowded band conditions.

As stated above, the beam uses Plumber's Delight type construction. For the newcomer's information, this type of construction has the antenna elements connected directly to the boom which in turn can be connected directly to earth ground without having any effect on the performance of the antenna. This is desirable because of the lightning protection offered by the system.

Fig. 20 is a drawing of the Delta-Loop driven element. The overall length around the driven element is slightly over one wavelength. Each side is approximately 1/3 wavelength long. The reason we say "approximately" is that the top section of the antenna is made of wire and is slightly shorter than 1/3 wavelength in order to put tension on the wire. A gamma-match feed system is used, eliminating the need for a balun.

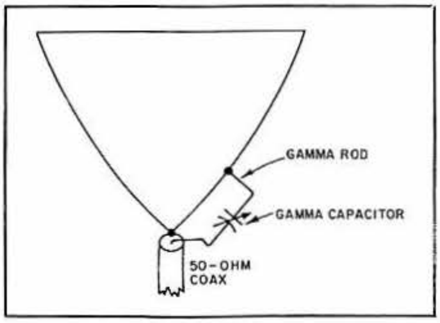


Fig. 20 — Basic configuration of the Delta-Loop driven element. Each side is approximately 1/3-wavelength long.

The formula used in figuring the driven element length is

$$\frac{1005}{f_{MHz}},$$

where f is the desired resonant frequency of the driven element. The answer will be in feet. The reflector length formula is

$$\frac{1030}{f_{MHz}}.$$

For a frequency of 21.2 MHz this figures out to a driven element 47 feet 5 inches (14.45 m) long and a reflector that is 48 feet 7 inches (14.81 m) long. Element spacing is approximately 0.2 wavelength or about 9 feet (2.74 m). Fig. 21 shows the two elements with the lengths of each segment.

Material Requirements

The beam elements were built primarily from Reynolds Do-It-Yourself aluminum tubing, which *should* be available from most hardware dealers. The reason we say "should" is because in some sections of the country hardware stores don't stock the tubing. However, most dealers will order the tubing for you. If you live in an area near or in a city of reasonable size, a look through the Yellow Pages will show any aluminum tubing dealers. The Reynolds

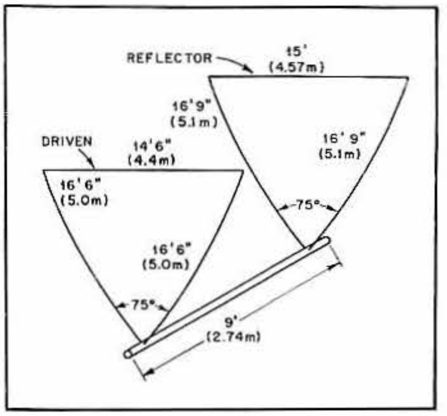


Fig. 21 — The element dimensions and the boom length. All measurements on the elements are made from where the element enters the boom; the portion of the element extending through the boom is not counted.

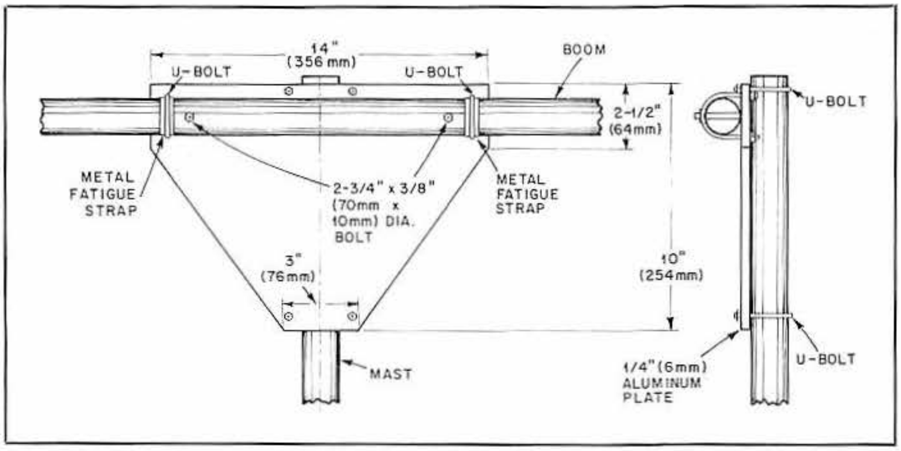


Fig. 22 — Construction details for the boom-to-mast mounting bracket. The U bolts holding the boom are 2-inch (51-mm) type. Those holding the mast will depend on the mast diameter — we used 1-1/2-inch (38-mm) U bolts for a 1-1/2-inch diameter mast.

Table 2

Shopping List

Quantity	*Length (ft)*	*Diameter (in.)*	*Reynolds no.*
4	8	1	4242
4	8	3/4	4222
2	6	7/8	4231
1	9	2	See Text.

3 feet of 3/8- or 1/2-inch diameter aluminum tubing.
12, 1-inch diameter hose clamps, stainless steel.
35 feet of no. 12 or 14 copper wire, solid or stranded.
1 variable capacitor, 100 pF maximum, 0.025 spacing or greater.
1 one-quart freezer container.
1 SO-239 Coax chassis connector.
5 1/4-inch diameter aluminum nuts and bolts, 1-1/4-inches long.

Feet X 0.3048 = m.
Inches X 25.4 = mm.

Do-It-Yourself tubing comes in 8-foot (2.44-m) lengths but most of the commercial tubing available from metal distributors comes in 12-foot (3.66-m) lengths. If you obtain the 12-foot types, be sure to specify type 6061 (61S) alloy as this material affords excellent strength for antenna elements. The boom used in this antenna was made from this alloy and is 2 inches (51 mm) in diameter with a 0.065-inch (1.65-mm) wall. Another source of aluminum or steel tubing is electrical supply houses; although this type of aluminum is a little too soft for the elements it would be suitable for a boom. Also, electrician's thin-wall steel tubing is available in various sizes, including the 2-inch diameter, for a boom. In a pinch, the boom could be made of wood, such as a length of 2 × 4. In such a case, the bottoms of the elements could be connected together with a length of wire to maintain the Plumber's Delight feature. The shopping list included here should prove of help in purchasing the parts.

Construction

The first step in building the antenna is to make up the vertical elements. The description given here is based on using the Reynolds tubing. Using a hack saw, cut the 7/8-inch (22-mm) tubing into 2-foot (0.61-m) sections. This particular type is made by Reynolds for the purpose of telescoping the 1- and 3/4-inch (25-mm and 19-mm) diameter sections together and comes in 6-foot (1.83-m) lengths. After cutting off four 2-foot (0.61 m) lengths you'll have one 4-foot (1.22-m) piece remaining. Cut this into four 1-foot (0.31-m) lengths and set these pieces aside for the time being.

Next, cut two lots, the thickness of the hacksaw blade, about 2 inches (51 mm) deep in one end of each of the 1-inch (25-mm) and 7/8-inch (22-mm) diameter lengths. Slide the 7/8-inch tubing inside the 1-inch diameter to a length of about 6 inches (152 mm) and then slip the hose clamps over the slots and tighten them. The 3/4-inch (19-mm) tubing can then be inserted into the slotted ends of the 7/8-inch (22-mm) tubing and these sections clamped with hose clamps. Two of the elements should be adjusted to the proper length for the driven element and two for the reflector, as per Fig. 21 (or whatever length you wish from the formulas). Some amateurs may prefer to cut their antennas for the cw portion of the band and others for the phone section.

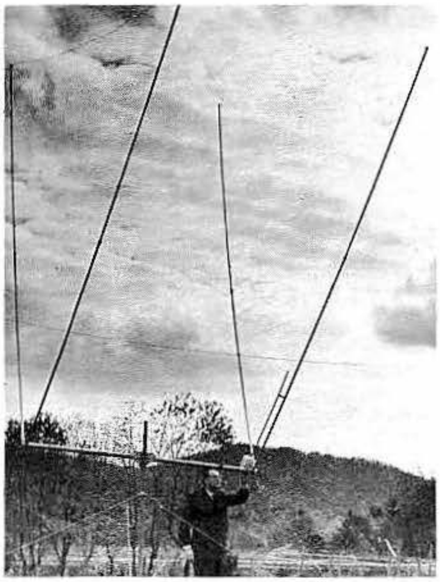
The next step is to cut the 1-inch (25-mm) holes in the boom to take the ends of the 1-inch diameter elements. We used a 1-inch chassis punch to make the holes, but a 1-inch metal reamer could also be used. The aluminum is easy to cut or punch so making the holes should be no problem. What can be a problem is lining up the holes so that the 75-degree angle between the elements is obtained. We made a jig from a piece of cardboard, using a protractor. Once one set of holes for the director and reflector were made the elements were temporarily mounted in the boom. The cardboard jig was laid on the elements and the 75-degree holes were marked off and drilled.

When the holes are all drilled, the boom can be laid on the ground and the element ends inserted into the boom holes. We allowed about 1/4-inch (6-mm) extension of the base of the elements through the boom so as to allow space for cotter-pin holes. However, before drilling the cotter-pin holes, insert the four 1-foot (0.31-m) lengths of the 7/8-inch (22-mm) tubing into the elements at the boom. This will serve to give added strength to the elements at the support point. Drill each of the four ends to take the cotter pins and install the pins. Tighten down the hose clamps on the top side of the boom to secure the elements in place.

Drill the tops of the elements to take the 1/4- × 1-inch (6-mm × 25-mm) aluminum bolts. The top wires can then be installed.

The close-up view shows the gamma installation. The gamma capacitor is mounted inside a plastic freezer container which is held in place by a small metal L-shaped plate mounted on the box and the boom, using four self-tapping screws. This plate also holds an SO-239 coax chassis fitting to take the feed line. We like to install an SWR bridge directly at the beam when making SWR or matching tests to reduce matching errors, and having the fitting there simplifies the procedure. The gamma rod, made from a length of 3/8-inch (10-mm) aluminum tubing 36 inches (0.91 m) long, is flattened at one end for a length of 1-1/2 inches (38 mm).The flatted portion is bent over at right angles and drilled to take one of the 1/4- × 1-1/4-inch (6-mm × 32-mm) aluminum bolts, which is mounted through the top of the freezer box. The gamma rod is held in place by this bolt and by the shorting bar between the rod and the element. The shorting bar is made from a piece of aluminum, 1 inch (25 mm) wide and long enough to fit around the two pieces of tubing and provide a separation of 3 inches (76 mm) between the rod and the elements.

How you mount the antenna boom to the supporting mast will depend a great deal on what type of tower or supporting structure you have. The method shown in the photo is a fairly simple one, and easy to make up. Fig. 22 shows details of the construction of the mounting unit. The one shown in the photo supporting the beam was made from two pieces of 1/16-inch (2 mm) thick aluminum plate. However, we found that even with the double plate there was still too much "give" in the mounting setup, so a replacement was made from 1/4-inch (6 mm) thick aluminum. This made the mount competely steady. Either a plate of 1/4-inch aluminum or 1/8-inch (3 mm) steel should be adequate for the jobs. The 2-inch (51 mm) U bolts that hold the boom to the mounting plate were adequate, but just for added insurance, 3/8-inch (10 mm), 2-3/4-inch (70 mm) long machine bolts (two required) were installed through the boom and mounting plate for greater holding strength.



This view shows the completed antenna being matched.

During our tests, a weather front moved through the area and we had wind gusts up to 40 mph plus icing and snow loading on the antenna. The antenna and elements showed very little movement in these winds, and the entire antenna appeared very strong.

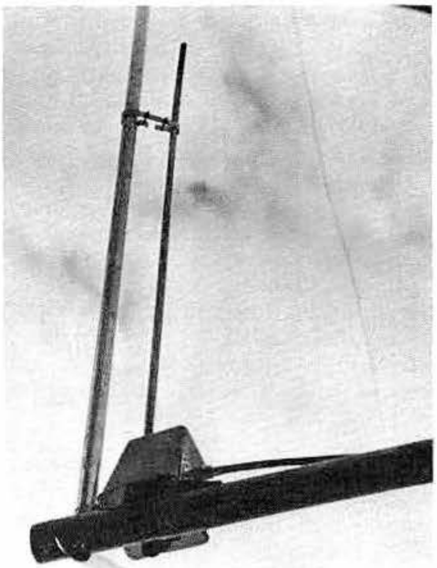
Adjustments

Adjustment of the gamma section is quite simple. Install an SWR bridge at the gamma feed point and tune up the rig on the desired frequency, Set the gamma shorting bar 24 inches (0.61 m) from the base of the gamma rod and tighten the gamma-bar nuts and bolts just enough to make electrical contact. Set the SWR bridge to read reflected power and adjust the gamma capacitor for a dip. The object is to find a setting of the capacitor and the gamma bar that gives a reading of zero in the reflected position. This may take a few tries, but you'll find the settings are not critical. If you adjust the antenna near the ground you may find it will require a new adjustment when it is up in its permanent location.

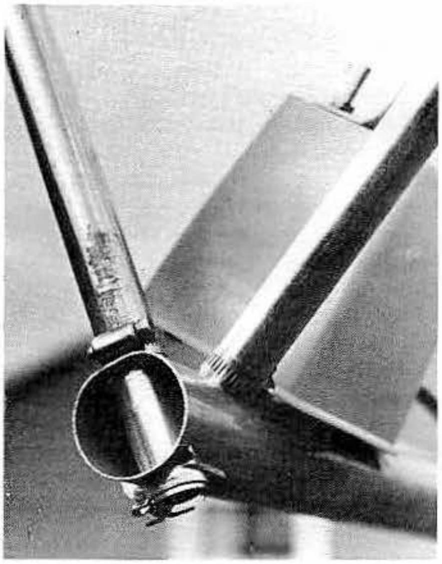
How you mount the antenna in its permanent location will depend on what you have to hold the antenna. If you use a boom mounting-plate-to-mast assembly such as already described, the U bolts holding the boom could be left slightly loose and the 3/8-inch (10-mm) bolts left out. The antenna could then be installed in an upside-down position and then rotated into place. Two men are better than one for this job, but one man *can* do the job. If a hole, say 1/2-inch (13-mm) diameter, is drilled through the boom a 1/2-inch rod could be slid through to serve as a lever to rotate the boom and antenna into an upright position and the U bolts and hardware could be then tightened down.

We think the Delta-Loop beam is an excellent antenna and offers many possibilities. Certainly the results obtained to this point prove the antenna is a real performer. Our tower is a crank-up job, making antenna testing a fairly simple project. The antenna was first matched at the 8-foot (2.44 m) level (boom height) and at the cranked-up height, about 55 feet (16.76 m) above ground. A very slight readjustment of the gamma capacitor was required at the greater height in order to get down to a 1-to-1 SWR. However, the change in SWR from the 8-foot to 55-foot (2.44- to 16.76-m) heights was very small. Also, the highest SWR was at 21,450 kHz, the top end of the band, with a mismatch no worse than 1.2 to 1. At 21,300 kHz the SWR dropped to 1 to 1 and remained at that figure all the way to the lower band edge.

The entire antenna weighs about 15 pounds (using the aluminum boom) so the antenna could be rotated with a heavy-duty TV rotator. One last note: We sprayed the cotter pins and hose clamps with a clear acrylic spray to reduce corrosion. This simple precaution should be taken in all antenna construction to prevent or reduce rusting. This material was originally presented in *QST* by Lewis G. McCoy, W1ICP.



The plastic freezer box is held in place by the small metal bracket which is attached to the boom with self-tapping screws. Also on the bracket is a coax fitting to take the RG-8/U coaxial feed line. The gamma rod is mounted on top of the box and is held to the element with the shorting clamp.



In this close-up view of the end of the boom, the mounting of the element ends are clearly shown. Cotter pins are used on the bottom end of the element and hose clamps on the top side of the boom. This secures the elements to the boom. The plastic freezer box that houses the gamma capacitor is clearly visible behind the elements.

Antennas for Travel Trailers and Campers

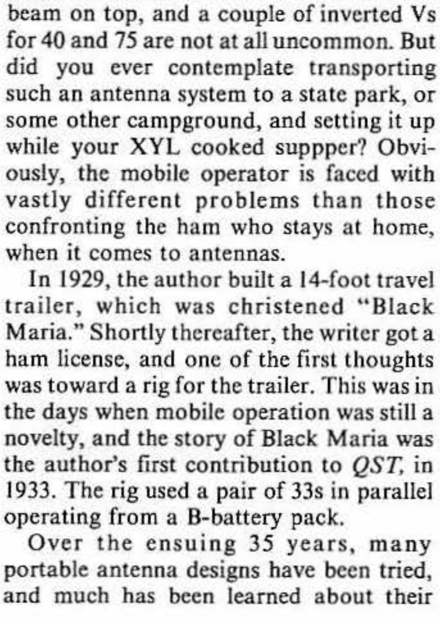
Pounding brass and rendering "lip service" from an RV or mobile home can be disappointing as all get-out if the antenna doesn't "play" well. Here are some tips for rig-mounted radiators that get the job done.

Who knows why so many hams like to go camping? Perhaps it's their Field Day training; perhaps it's the next logical step after mobile operation, or perhaps they just cannot leave home without their rigs. At any rate, it is nice to have your own means of communication with the outside world when you are away from home in the Maine woods, at the Grand Canyon, or even down in Mexico.

One thing all hams know is that no matter how good a transmitter you may have, you cannot get out without an antenna; and the better the antenna is, the better you get out. The antenna is usually no problem for the home station. The sky is the limit, so to speak. A 65-foot (19.81 m) crank-up tilt-over tower with a triband beam on top, and a couple of inverted Vs for 40 and 75 are not at all uncommon. But did you ever contemplate transporting such an antenna system to a state park, or some other campground, and setting it up while your XYL cooked suppper? Obviously, the mobile operator is faced with vastly different problems than those confronting the ham who stays at home, when it comes to antennas.

In 1929, the author built a 14-foot travel trailer, which was christened "Black Maria." Shortly thereafter, the writer got a ham license, and one of the first thoughts was toward a rig for the trailer. This was in the days when mobile operation was still a novelty, and the story of Black Maria was the author's first contribution to *QST*, in 1933. The rig used a pair of 33s in parallel operating from a B-battery pack.

Over the ensuing 35 years, many portable antenna designs have been tried, and much has been learned about their relative performance. The degree to which a trailer traveler is restricted in a choice of an antenna varies widely, of course, depending upon the facilities available at each stopping point. These are seldom known in advance, but to get the most out of the equipment, the trailer operator should be prepared to take maximum advantage of whatever facilities he may find on each occasion.



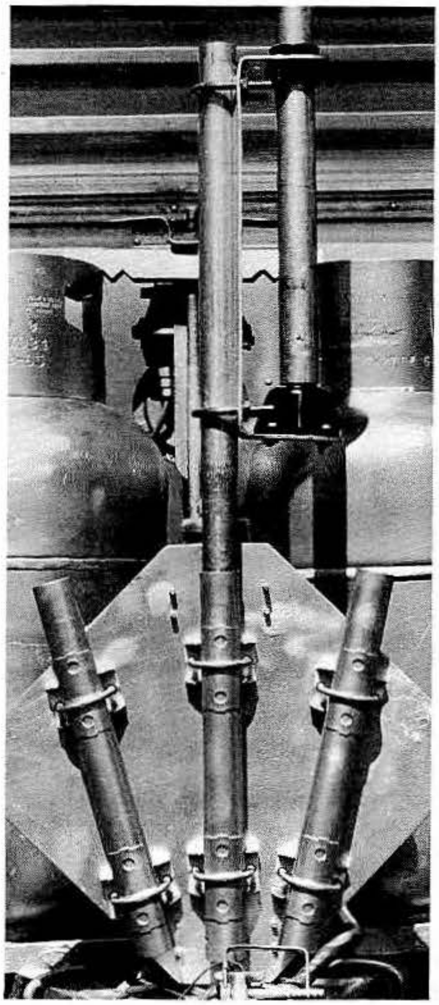
The author's 30-foot (9.14 m) Airstream trailer with the 75-meter Airstream Loop in place. The "tuning" mast is the one carrying the flag.

Dipole Antennas

Long ago, it was found that a simple dipole for 40 or 75 would far outperform the author's mobile whip, even with the dipole only a few feet above ground. While writing this, sitting in the latest Black Maria — a 30-foot Airstream job — up in Port Colburne, ON, the author was listening to the 75-meter phone band. The dipole is only 8 feet (2.44 m) above ground. When checking into the Airstream Travel Trailer Net, which meets every Sunday on 3963 kHz at 8 A.M. local time, the writer worked other trailer stations in Connecticut, New Jersey, Maryland, Pennsylvania, New York and Ohio. Several times the author switched to the mobile whip and could not be heard through the QRM. Such a dipole can be prefabricated and, when rolled up, occupies very little storage space.

When the length of the stay warrants it, and trees or other supports are available, the antenna will be even more effective when raised to a respectable height. A bow and arrow is kept on hand for shooting lines over taller trees. Incidentally, Hy-Gain makes a deluxe portable dipole consisting of two stainless-steel tapes in a double plastic housing. The tapes are calibrated in meters, and can be quickly reeled out to the proper length for use on any desired band. The unit is fitted with a coax connector, making installation very easy.

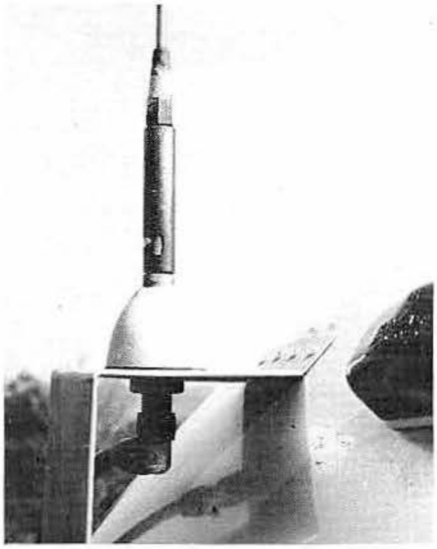
If only a single support is available, the dipole can be used in "inverted-V" fashion. A convenient way of putting up such an antenna is to use three or four 5-foot (1.52 m) lengths of 1-1/4-inch (32 mm) aluminum TV masting as a center pole, mounting it on the front of the trailer. The author has a mounting for such an arrangement clamped to the bumper, as shown in one of the photographs. The mast can be equipped with light nylon halyards for hoisting the center of the dipole. The ends of the dipole can be attached to whatever may be handy, but the higher, the better.



Insulated mounting at one end of the "Airstream Loop" 75-meter antenna. The "tuning" mast can be mounted directly in one of the other sockets. The tuning will vary with the spacing between masts as well as the length of the "tuning" mast. The insulated mounting can be transferred to one of the side sockets to obtain maximum spacing.

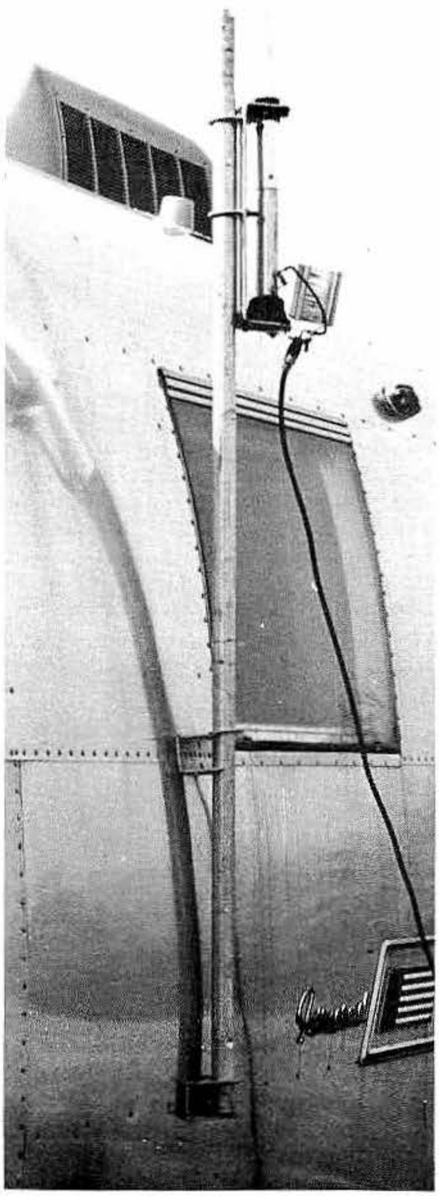
Loaded Antennas

Of course, there are many times when the surroundings, or the shortness of the stopover, make erection of a conventional dipole impractical. On these occasions, the author used one or another of several arrangements shown in the accompanying photographs and sketches. Where the



An elevated mounting for a mobile whip at a top rear corner of the trailer body. The bracket is fastened by pop rivets. This point may also be used, with the whip removed, for feeding wire dipoles.

A check with a 20-watt fluorescent lamp by W1WKZ indicates the "hot" points on the Airstream Loop 75-meter antenna system.



A 25-foot (7.62 m) base-loaded antenna mounted on brackets attached to the side of the trailer.

antenna system is one that requires a ground for operation, it was found that a quarter-wave wire counterpoise connected to the trailer, and strung out a few feet above ground, is usually a much better "ground" than the trailer alone, even if the trailer is actually grounded to a driven rod. The author carries two each of wires cut to lengths of 8, 16, 32 and 60 feet (2.44, 4.88, 9.75 and 18.29 m) for use as counterpoise on the 10-, 20-, 40- and 75-meter bands, respectively. One end of each wire is fitted with a large battery clip, while the other is terminated in an insulator. Trailer awning poles come in handy as counterpoise supports when nothing else is available.

"Airstream Loop" Antenna

Of particular interest is the 75-meter folded configuration shown in the sketch of Fig. 23, which is called the "Airstream Loop," although, strictly speaking, it does not function as a true loop. With the fittings that are provided, this antenna can be put up in a few minutes, and its performance seems to be about equal to that of a low dipole. It has the advantage that it is completely supported by the trailer, and requires no external supports. It is contained entirely within your own campsite. There are no wires strung out for you or your neighboring campers to trip over or be garroted by in the dark. A 30-foot (9.14-m) length of wire is strung between, and connected to, two poles made of aluminum TV mast sections. A third mast (A), of approximately the same length as the others, and connected to the trailer, is an essential part of the system. This arrangement appears to work as a folded half-wave antenna, the 30-foot (9.14-m) wire and the two poles connected to it forming one half of the antenna, while the other half is formed by the trailer body and mast (A). Probing with a fluorescent lamp shows that the end of the trailer opposite the feed point is "hot" while the feed-point end is "cold." The system can be tuned by adjustment of the length of pole A, and/or changing the spacing between A and the adjacent pole. The spacing can be changed by a selection of the pole mounting sockets shown in one of the photographs. In this manner, the resonant frequency can be changed by almost 150 kHz. For any adjustment, the transmitter can be tuned about 30 kHz either side of the resonant point before the SWR exceeds 3 to 1. Since the "hot" end of the trailer is the front end in my case, the tow car must be unhitched, and an insulating block used under the customary supporting jack.

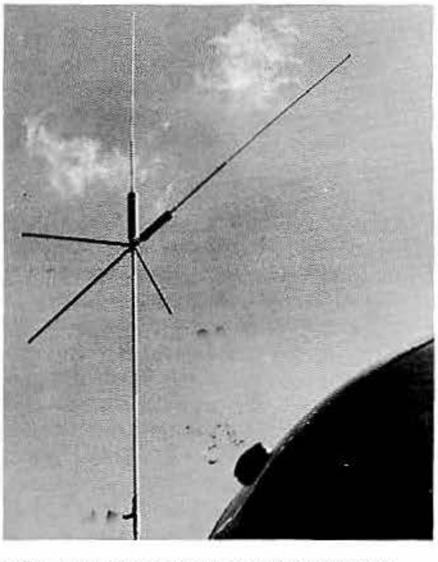
In a similar arragement for 40 meters, mast A is omitted, and a wire approximately 21 feet (6.40 m) long is connected to the pole at the feed-point end. The open end of the wire is supported from the pole at the opposite end of the trailer by a length of nylon rope.

40-Meter Monopole

Another 40-meter antenna that has been used with considerable success is a 34-foot (10.36 m) length of 300-ohm ribbon line connected as a folded monopole, and strung up in the same manner as the antenna just described. One conductor of the ribbon is grounded to the trailer at the feed point, while the other conductor is connected to the center conductor of the coax line. The two ribbon conductors are connected together at the far end.

Matching

Standing-wave ratios up to 5 or 6 to 1 are hardly worth worrying about at 4 MHz so



A five-band antenna system. A New-Tronics mobile antenna base section is fitted with a Waters Add-a-Band adapter. The short resonators for 10, 15 and 20 meters are Waters. The 80-meter resonator (top) is New-Tronics. A threaded stud has been added to the vacant side of the adapter to take a New-Tronics 40-meter resonator. The system is fed at the base with a single coax line.

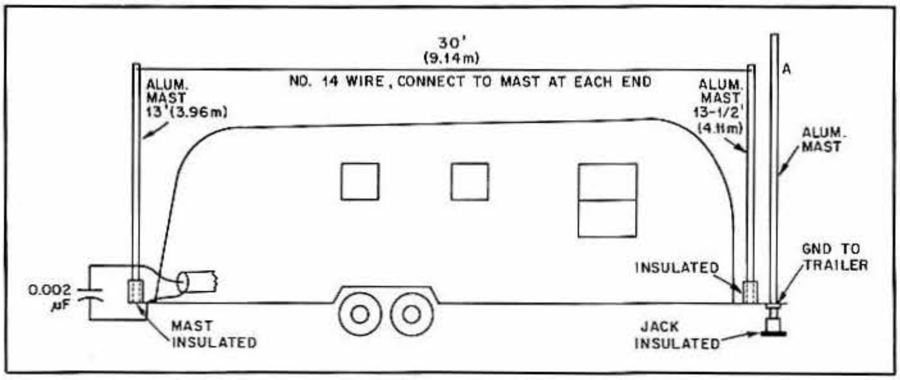
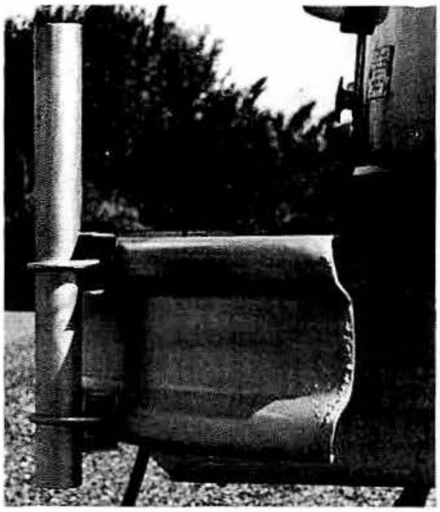
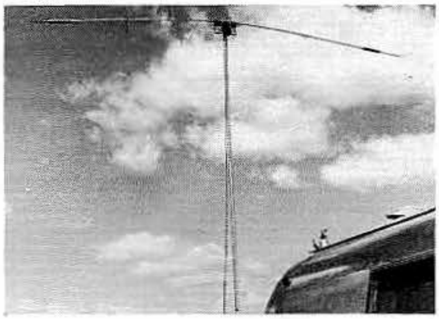


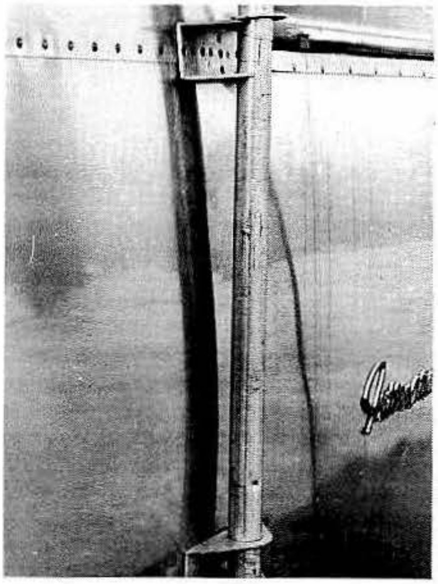
Fig. 23 — 75-meter "Airstream Loop"



A bumper-mounted socket for TV masting.



An 80-meter dipole made of two New-Tronics 75-meter mobile whip back to back. The 15-foot (4.57 m) mast is bumper-mounted. A 1-to-1 balun is mounted on the center insulating panel, which is secured to the mast with U bolts. This antenna is quite narrow-band when operated on 75 meters, making it necessary to retune the antenna for excursions of more than 30 or 40 kHz.



Brackets for mounting TV masting on the side of the trailer. The upper bracket is fitted with a removable U-shaped yoke bolted to the bracket. The brackets are fastened to the trailer with pop rivets.

far as additional power loss is concerned. However, an SWR greater than 1 to 1 causes the line input impedance to vary, depending on the length of the line. The output circuits of many transmitters and transceivers are not designed to work into loads departing significantly from 50 ohms. With these units, it may not be possible to load the final stage, or components in the output stage not designed for the voltages that develop with higher-impedance loads may be damaged. Use a Monimatch, or other reflectometer, and adjust the antenna for minimum SWR. The author carries along several mica capacitors ranging in value from 50 pF to 0.002 μF with battery clips attached, which are used to shunt the line at the feed point. Start out with the lowest value, and double the capacitance in steps until you get an SWR of 1 to 1 somewhere in the band, and then adjust the antenna length for resonance at the desired frequency.[1]

To get some idea of the relative performances, a series of checks was made at 3825 kHz on several of the antennas described. A receiver with a horizontal antenna was set up at a distance of eight miles from the trailer, and S-meter readings were taken with the results shown in the accompanying tabulation. All readings were made with identical input power to the transmitter, and with the antennas adjusted for an SWR of 1 to 1.

Table 3

Hustler 75-meter mobile whip mounted vertically on top rear corner of trailer	S7
Same as above, with 60-foot counterpoise wire connected to trailer	S9
Two Hustler 75-meter mobile whips back to back as a horizontal loaded dipole	S9 + 5 dB
60-foot horizontal wire 8 feet high, using trailer as ground	S9 + 10 dB
Hustler 4BTV trap vertical with 75-meter resonator	S9 + 10 dB
120-foot dipole, 15 feet high at center	S9 + 20 dB
"Airstream Loop" antenna	S9 + 20 dB
Home-station dipole 50 feet high	S9 + 30 dB

Feet = 0.3048 = m.

To sum it all up:

1) Carry a complete set of mobile whips for lunch stops, or other occasions where you just do not have the time or room for anything better.

2) If at all possible, use a 1/4-wave counterpoise clipped to the trailer when using a mobile whip.

3) If you have the time or space, clip a 1/4-wave wire, instead of a whip, to your mobile antenna mount, and run it out to a bush or tree.

4) In addition to (3), clip a 1/4-wave counterpoise to the trailer, and run it in the opposite direction.

5) If you are stopping for a short time, or for the night, rig up the 5-band mobile whip with five 1/4-wave counterpoises, one of appropriate length for each band.

6) If you want to concentrate on one band, put up the 16-foot (4.88 m) mobile-whip dipole, if your space is limited.

7) If you have plenty of room, put up a 1/2-wave dipole for your favorite band.

8) If you want to work all bands, and space for dipoles is limited, then put up your trap vertical with the 75-meter resonator tuned to your favorite frequency.

9) If you are going to spend a week in a particular campground, shoot some lines over a couple of high trees with a bow and arrow, and get your dipoles up in the air as high as possible.

10) The use of balloons and kites is good, but depends completely on the wind.

11) Next best to a high dipole, put up the "Airstream Loop" antenna for 75 meters.

12) If all else fails, bring your 2-kW PEP linear and your 2.5 kW ac gas generator along. This will at least keep the other campers awake. Don't forget a low-pass filter for TVI! This material was originally presented in *QST* by Philip S. Rand, W1DBM.

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[1] [Editor's Note: This method is equivalent to the use of a stepdown L network. It can be used when the antenna feed-point impedance is lower than the line impedance. To obtain a match, the antenna length must be somewhat longer than a resonant length, so that the antenna shows inductive reactance at the feed point. (This reactance serves as a substitute for the reactance of the coil of a conventional L network.) For an accurate match, it is necessary to adust the antenna length and the value of the capacitor until the appropriate transformation ratio is obtained.]

The Apartment Dweller's Dilemma

Having trouble getting a signal out from "concrete city"? Nonresonant, random-length wires can provide surprising results if a Transmatch is used to make the rig happy with the load it sees.

It is apparent that many would-be amateurs living in apartment buildings believe it is impossible to get an effective signal on the air. They feel the need to have an outdoor antenna in order to make contacts. This isn't true. Of course, the apartment dweller can always go mobile, but there comes a time when the amateur wants a home station. This article treats the problem and, hopefully, will get a few more hams on the air.

Some General Considerations

There are exceptions to the following rules but, in general, they can be depended upon.

1) An outdoor antenna will work better than an indoor one.

2) An antenna inside a frame building with wood exteriors is better than the same antenna in a steel-and-concrete building.

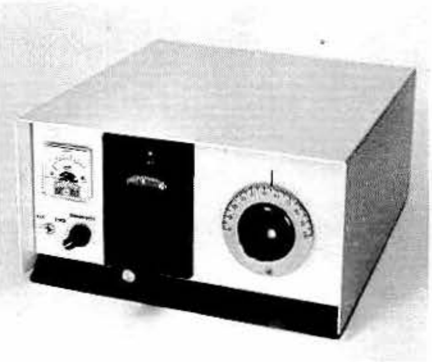
3) The higher above ground, inside or out, the better the antenna will work.

4) The bigger (or longer) you can make an indoor antenna, the better — even if it means running the wire around corners.

5) Even a poor antenna *should* produce some contacts.

The Coupling Problem

Most transmitters are designed to work into a 50-ohm load, and contain little or no provision for adjusting the transmitter when the load is other than 50 ohms. Unfortunately, there is no random-length wire antenna that will present a 50-ohm load on all bands. What is required is a Transmatch. A Transmatch is simply an adjustable LC network that converts the unknown antenna impedance to 50 ohms. This unit, shown in Fig. 24 and the photographs, will cover the 80- through 10-meter bands and can handle 1 kW of rf power. In addition to matching the transmitter to the antenna load, the Transmatch helps reduce harmonic radiation. Many Novices get in trouble with the FCC because of 2nd-harmonic radiation from the 80-meter signal. This unit should reduce such harmonic radiation. Also, the use of a Transmatch can provide better front-end selectivity for the receiver. Some receivers are subject to severe cross modulation when operated near a broadcast station. The Transmatch should reduce this effect.



The completed Transmatch. The counter dial and knob are James Millen Mfg. Co., Inc. products. Check with G. R. Whitehouse, Amherst, NH 03031.

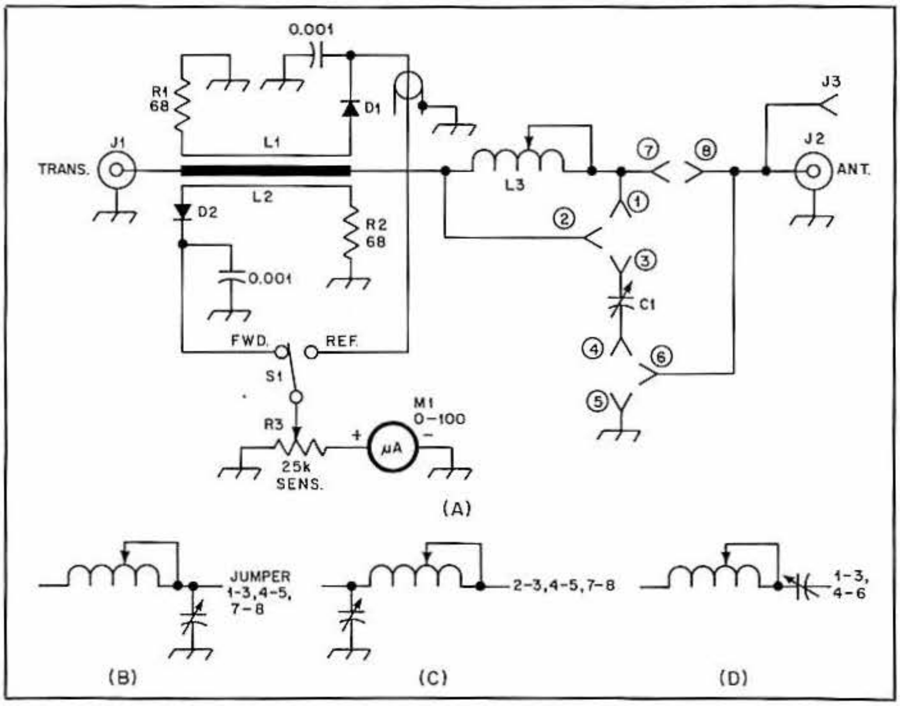


Fig. 24 — Circuit diagram of the L-network Transmatch. The eight banana jacks are E. F. Johnson type 108-900, and three dual banana plugs are required, E. F. Johnson type 108-200.

C1 — Variable capacitor. 350 pF (E. F. Johnson 154-10).

D1, D2 — 1N34A germanium diode.

J1, J2 — Chassis connector, type SO-239.

J3 — Feedthrough terminal, isolantite.

L1, L2 — See Fig. 25, part of etched circuit assembly.

L3 — Variable inductor, 28 μH (E. F. Johnson 220-203).

M1 — 100-μA meter.

R1, R2 — 68-ohm, 1/2-watt carbon or composition, *not wirewound.*

R3 — 25,000-ohm carbon control, linear taper.

S1 — Spst toggle.

Circuit Details

The unit shown in Fig. 24 is designed to be used in three configurations. They are shown at B, C and D. With one of the three hookups, it should be possible to match practically any antenna to the transmitter.

In order to get complete band coverage and avoid the complexities of bandswitching, banana and jack plugs are used to change the circuit to the configuration needed. For example, if one wanted the setup shown at B, he would jumper terminals 7 and 8, 1 and 3, and 4 and 5. Using the banana plugs makes for easy changing of the circuit.

Whenever a Transmatch is used, the operator should have a way of knowing when the unit is adjusted correctly. The answer to this need is a Monimatch or other SWR indicator. If you have an SWR meter, it can be connected in the line between the transmitter and the coupler. If

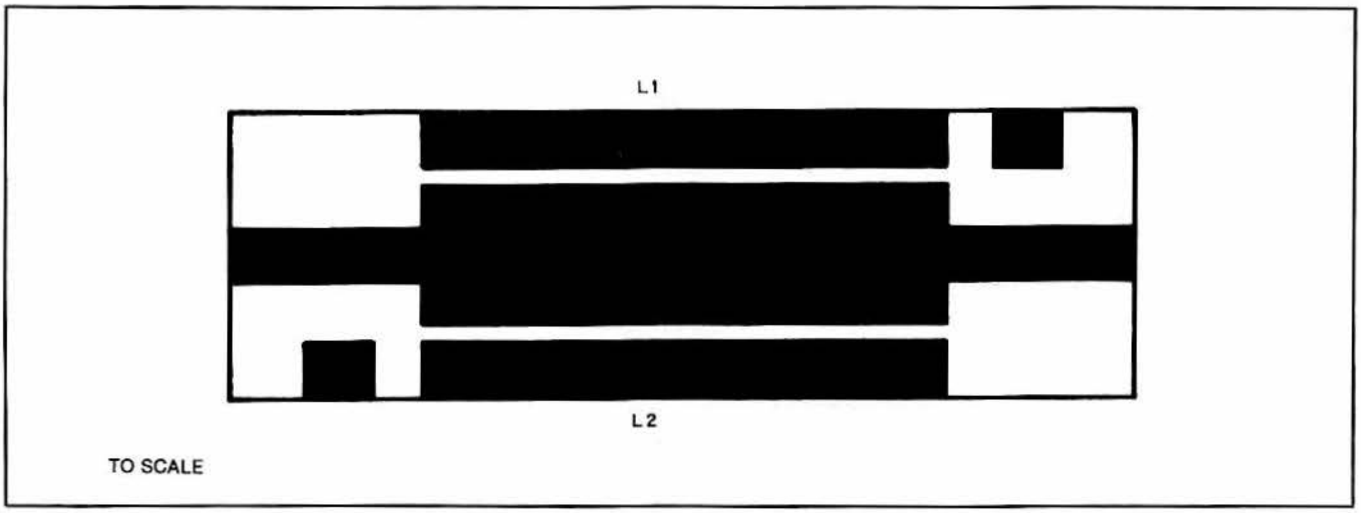


Fig. 25 — Etched circuit-board template. The foil side is shown, with etched portion shaded.

not, you can build the Monimatch[1] shown in Fig. 24, and include it in the cabinet with the Transmatch.

Construction Details

The chassis for mounting the Transmatch is made from a piece of aluminum measuring 10 × 19 inches (254 × 482 mm). The ends of the 19-inch length of aluminum are bent up to form a U-shaped chassis, the ends being 4-1/2 inches high to form a chassis 10 × 10 × 4-1/2 inches (254 × 254 × 114 mm). The back side of the U has an opening cut out, 3-1/4 inches high by 4-1/2 inches (83 × 114 mm) long. A piece of Plexiglas is mounted over this opening. The jack-plug sockets are installed directly on the plastic. Connections from the roller inductor, L3, and variable capacitor, C1, are made to the banana jacks. Be careful when drilling the holes for the jacks to insure that they will mate with the plugs. Fig. 25 shows the details for a pc-board Monimatch.

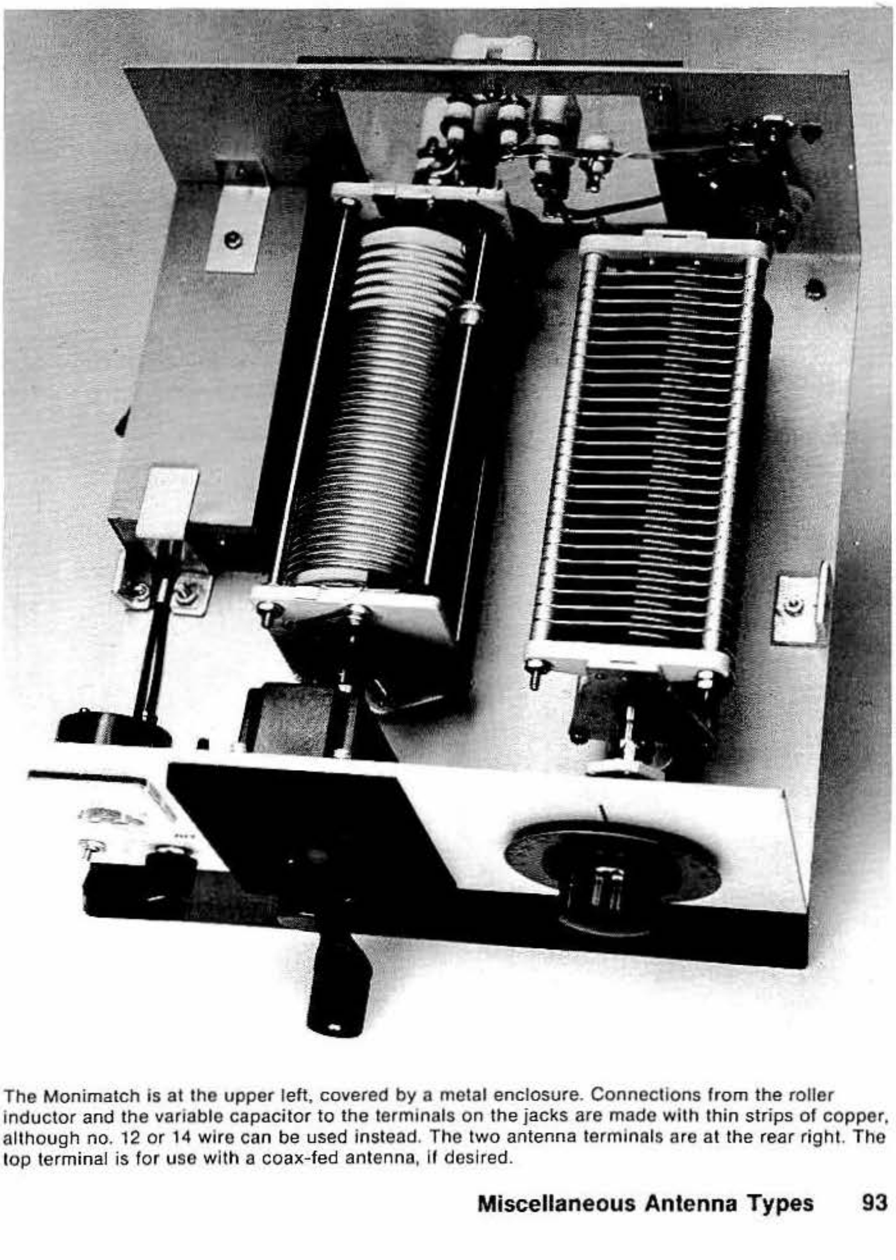
Methods for making etched circuit boards are given in detail in the construction chapter of The Radio Amateur's Handbook, so we won't treat the process here. When installing D1 and D2 on the board, be sure to use a heat sink while soldering the leads. Too much heat can ruin the diodes. Shielded leads are used from the circuit board to S1 to prevent unwanted rf pickup.

Today's equipment builder soon finds out that locating parts can be a tough problem. Fortunately, we have found a distributor who will furnish all the parts. With the exception of the chassis, the parts for the Transmatch can be purchased from Barry Electronics.[2]

Some Antenna Ideas

With this Transmatch one should be able to match any random-length antenna to his transmitter. To test the system, we strung up 25 feet (7.62 m) of wire in the ARRL lab (a steel-and-concrete building, first floor). The Transmatch provided the desired 50-ohm impedance on all bands. We didn't get any "60-over-9" reports, but we *did* make contacts.

As to your antenna installation, we suggest running the wire up to the ceiling, around the room, perhaps into the next room, making the antennas as long as possible. If the XYL objects to the wire, use an invisible antenna. Nope, we're not



The Monimatch is at the upper left, covered by a metal enclosure. Connections from the roller inductor and the variable capacitor to the terminals on the jacks are made with thin strips of copper, although no. 12 or 14 wire can be used instead. The two antenna terminals are at the rear right. The top terminal is for use with a coax-fed antenna, if desired.

joking! You can make the antenna from no. 26 or 28 wire, which will be practically invisible. Also, you can conceal the wire behind molding. Be sure to insulate the wire if it runs near any metal. In some cases, it is impossible to get the wire outside. However, if you have a screen in one of your windows, terminate the end of the antenna at the screen. The screen *is* outside and it will help the system radiate. While it may be difficult to install, the antenna length to shoot for is approximately 120 to 130 feet (36.58 to 39.62 m) because this is a good length for multiband operation.

If you cannot put an antenna on the apartment roof, there is still a trick or two for having an outside antenna. You can drop a wire out the window and let it hang down. How long the wire should be will depend on how high up you are. You can make the wire long enough to reach nearly to the earth, but high enough to be beyond the reach of passersby. *Safety first,* always! There is no electrical law that states that a vertical must be fed at the bottom. Just connect the end of the wire to your Transmatch and tune up the system. You can use small-diameter wire. Use a lead sinker on the end of the wire and possibly imbed the sinker in a small sponge-rubber ball. (That way, you won't break your neighbor's window.)

If there is a support to which you can attach the far end of the antenna you can use the invisible-wire trick. Use rubber bands for insulators. Erect no. 26 or 28 wire. Don't be too discouraged if the wire gets broken by passing birds!

We know one ham who lived in a basement flat. He ran a wire through the wall to the bottom of a rain gutter, tuned up the system, and managed to work DXCC. (Safety first, again. The downspout should be beyond the reach of human beings!) The general idea is to use ingenuity. With a Transmatch you never can tell *what* will prove to be a useful antenna.

How to Tune Up

Using the Transmatch is not complicated. Although it takes some time to find the correct combination of settings, once determined, they can be logged for later reference. Use a short length of 50-ohm coax to connect the Transmatch to the transmitter. Attach the antenna to the Transmatch. Tune up your transmitter on the desired band, making sure that the final amplifier is resonated, but with the power output reduced. With the Monimatch in the forward-reading position, set the sensitivity control for a full-scale reading. You may have to increase the output of the transmitter to get full deflection, but be sure to keep the final amplifier tank in resonance. Switch the meter to the reflected position, and then adjust L1 and C1, until you get the lowest indication of reflected power. It should be possible to get the meter to read zero. When you have a zero reading in the reflected position, versus full scale in the forward setting, the Transmatch is correctly adjusted, and the SWR is 1. You may have to change the circuit to one of the other configurations in order to get a match, but one combination should work. Once you have the Transmatch set properly, you can then adjust the transmitter to its rated power input. One other point: It isn't always possible to get a good ground connection in an apartment. Therefore, a connection to a cold-water pipe or earth ground should be used. This material was originally presented in *QST* by Lewis G. McCoy. W1ICP.

References

[1] McCoy, "An Etched-Circuit Monimatch for Checking Your Antenna System," *QST*, October 1969. (See Chapter 5.)

[2] Barry Electronics, 512 Broadway, New York, NY 10012.

A 40-Meter DDRR Antenna

This antenna consists of a 1/4-wavelength element grounded at one end and wound into a single-turn coil, a few conductor diameters above the ground (see Fig. 26).

Shortly after the author's article on a practical DDRR Antenna appeared,[1] a number of inquiries were received regarding low-frequency versions of this antenna for operation at ground level. After a little experimenting, the author came up with this version of a 40-meter DDRR which works quite well. In early tests very fine QSOs were held with stations as far away as Phoenix, while the antenna was located inside the garage and surrounded by myriad metallic objects. When the antenna was relocated to the backyard, marked improvement was noted, even though this antenna site was marred by a sharp rise of 4 feet (1.22 m) in ground elevation, plus close proximity to house wiring and power lines. In spite of these obstacles solid contact was easily achieved with stations up and down the West Coast. Encouraged by these results, we moved the antenna to a rooftop location which put it well in the clear insofar as metallic objects above the groundplane were concerned. In this location, the DDRR really proved its worth. In spite of its low profile, a little over 1 foot (0.31 m), and its very small span, a few inches over 9 feet (2.74 m), it was more than adequate when competing with any signal on the band. The obvious conclusion from my experiments is that the 40-Meter DDRR is the apartment-dweller's dream. It is principally for that group that this article is prepared. Other interested amateurs might be those who are limited, as this author is, by too much house on too little real estate; or those who for other reasons cannot cope with high towers, masts and guy wires.

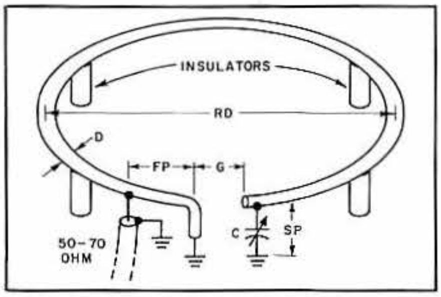
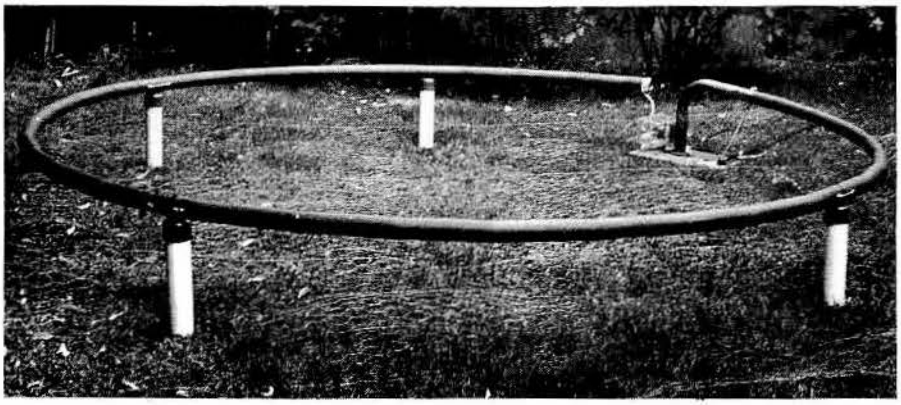


Fig. 26
RD = 0.078 λ (28°)
SP = 0.11D (2.5°)
FP = 0.25 h (See Note 1)
C = (See Note 2)
D = (See Note 3)
G = (See Table 4)

Notes: (1) Actual dimension must be found experimentally. (2) Value to resonate the antenna to the operating freq. (3) d ranges upward from 1/2" (13 mm). The larger "d" is the higher efficiency is. Use largest practical size, e.g., 1/2" (13 mm) for 10 meters, 5" (127 mm) or 6" (152 mm) for 80 or 160 meters.

Before this writer's enthusiasm sends you out to rip down your inverted V or to dismantle your beam, remember this: The DDRR, for all of its capabilities, will not supplant a full-size single-frequency antenna which is properly erected over clear terrain. What it will do is provide an



The chicken-wire groundplane is evident in the background. The base plate can be seen at lower right. Note the relative positions of the 52-ohm coaxial feed at the left end of the plate, the flange on the foot of the post, and the tuning unit at the right-hand end of the plate.

The braided lead across the flared joint is to assure electrical continuity. The screws used are self-tapping sheet-metal screws. The top end of the insulator (2-inch [51 mm] diameter PVC pipe) is a standard PVC pipe cap; the bottom is closed off with a cap from an aerosol can (2-inch [51 mm] ID).

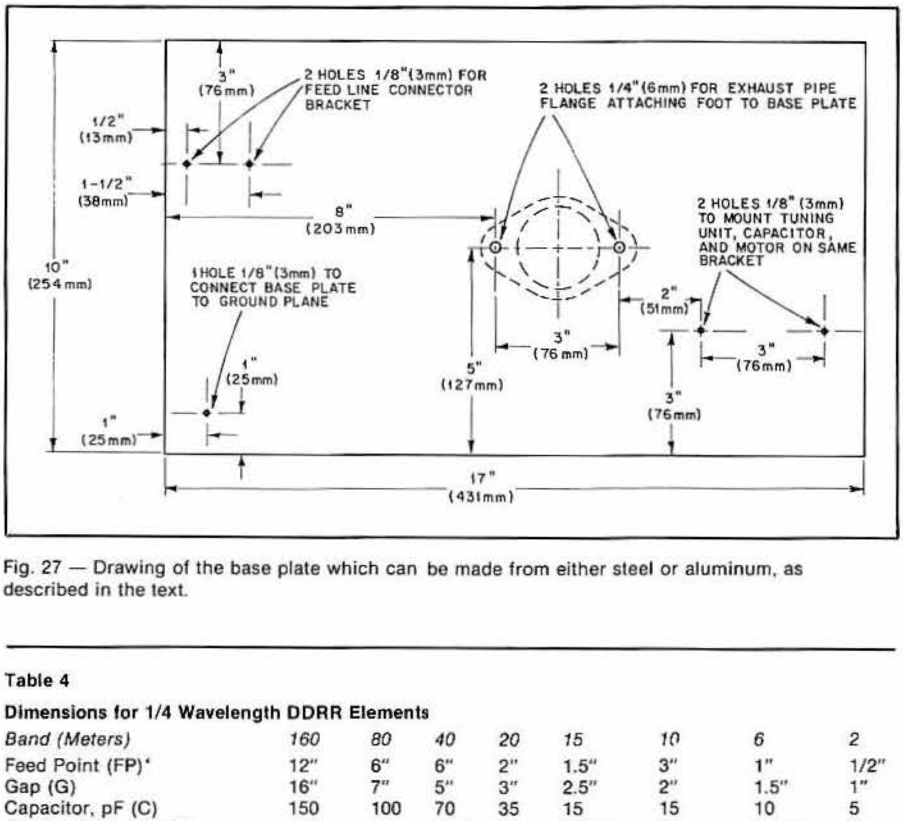

3"
(76mm)
2 HOLES 1/8"(3mm) FOR FEED LINE CONNECTOR BRACKET
2 HOLES 1/4"(6mm) FOR EXHAUST PIPE FLANGE ATTACHING FOOT TO BASE PLATE
1/2"
(13mm)
1-1/2"
(38mm)
8"
(203mm)
2 HOLES 1/8" (3mm) TO MOUNT TUNING UNIT, CAPACITOR, AND MOTOR ON SAME BRACKET
10"
(254mm)
1 HOLE 1/8"(3mm) TO CONNECT BASE PLATE TO GROUND PLANE
2"
(51mm)
3"
(76 mm)
3"
(76mm)
1"
(25mm)
5"
(127mm)
3"
(76mm)
1"
(25mm)
17"
(431mm)

Fig. 27 — Drawing of the base plate which can be made from either steel or aluminum, as described in the text.

Table 4

Dimensions for 1/4 Wavelength DDRR Elements

Band (Meters)	*160*	*80*	*40*	*20*	*15*	*10*	*6*	*2*
Feed Point (FP)*	12"	6"	6"	2"	1.5"	3"	1"	1/2"
Gap (G)	16"	7"	5"	3"	2.5"	2"	1.5"	1"
Capacitor, pF (C)	150	100	70	35	15	15	10	5
Spacing (Height) (SP)	48"	24"	11"	6"	4 3/4"	3"	1 1/2"	1"
Tubing Diameter (D)	5"	4"	2"	1"	3/4"	3/4"	1/2"	1/4"
Ring Diameter (RD)	36'	18'	9'	4.5'	3'4"	2'4"	16 1/4"	6"

*See Fig. 26 for explanation of designations.

Feet X 0.3048 = m.

Inches X 25.4 = mm.

antenna which will enable communications of respectable quality, where heretofore it has been impossible because of inadequate space to erect a 40-meter antenna.

Some consideration should also be given to the fact that the high-Q nature of the DDRR and its resultant narrow-band characteristics serve to reduce the noise level. Boyer[2,3] reports that in the initial experiments it was found that DX stations which could copy signals from either a vertical or a DDRR could only be heard on the DDRR due to the reduction in background noise. So if you have a noisy location, it might be to your benefit to try the DDRR, regardless of what antenna you are presently using.

Constructing the 40-Meter DDRR

In this application, 2-inch (51 mm) diameter automobile exhaust pipe was used as the radiating element. The local muffler shop not only supplied the material, but also undertook to bend it to specifications. This was an obvious course since the material and the power bender were right at hand.

The dimensions for 40 meters are:

Ring — 9 foot (2.74 m) diameter, center to center.

Height — 12 inches (0.31 m) from ground plant to element center.

Gap — 6 inches (152 mm) from upright post center to open end of ring.

In forming the ring to these dimensions, four 10-foot (3.05 m) lengths of tubing were used. A 10-degree bend was made at 9-inch (229 mm) intervals in three of the lengths. The fourth length was similarly treated, except for the last 18 inches (0.46 m) which were bent at right angles to form the upright leg of the ring. One end of each section was flared so that the sections could be coupled together by slipping the end of one into the flare of its mate.

The required flares are easily made at the muffler shop with the aid of the forming tools. Another task which can best be completed at the shop is to weld a flange onto the end of the upright leg. This flange is to facilitate attaching the leg to the mounting plate which provides a chassis for the tuning mechanism and the coaxial-feed coupler. After bending and flaring is complete, the ring is assembled and minor adjustments made to bring it into round and to the proper dimensions. This can best be done by drawing a circle on the floor with chalk and fitting the ring inside the circle. The circle must be slightly larger than the center-to-center diameter so that the reference line can be seen easily. For example, with two-inch (51-mm) tubing the actual diameter of the reference circle must be 9 feet, 2 inches (2.79 m). When you

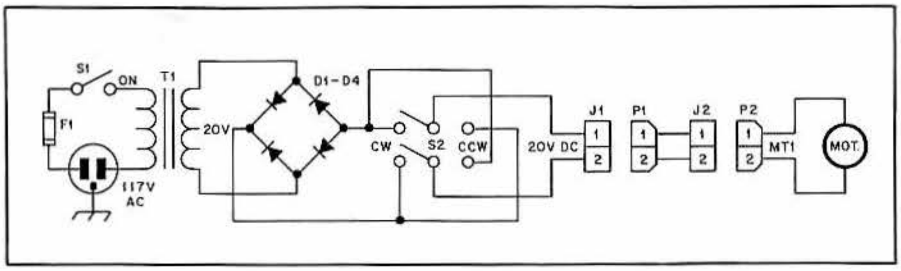
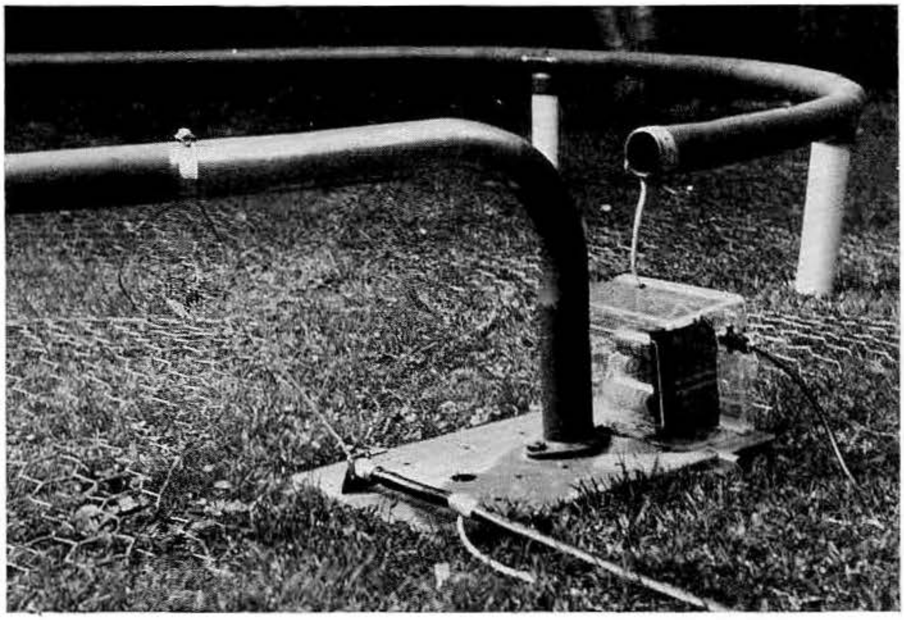


Fig. 28 — Circuit diagram of the power supply and control motor.

D1 through D4 — 1 A, 50 PRV, or equiv.
F1 — Fuse, 1 A.
J1, J2 — Two-terminal jack.
MT1 — Motor (see text).
P1, P2 — Two-terminal plug.
S1 — Spst.
S2 — Dpdt, center off.
T1 — Transformer (see text).



Clamps used to connect the feed line and the open end to the capacitor are standard hose clamps. The heavy black lead, center to lower right, is the 52-ohm feed line. The smaller line coming from the plastic housing is the motor control line.

have a satisfactory fit between the tubing ring and the chalk ring, drill a 1/4-inch (6-mm) hole through each of the joints to accept a 1/4-inch bolt. These bolts will clamp the sections together. Also, they can be used to attach the insulators which support the ring at a fixed height above the groundplane.

Making and Attaching the Insulators

Insulators for the antenna were made from 11-inch (279-mm) lengths of 2-inch (51-mm) PVC pipe inserted into a standard cap of the same material. The PVC caps are first drilled through the center to accept the 1/4-inch (6-mm) bolt previously installed at the joints. The caps are then slipped onto the bolts and nuts are installed and tightened to secure the caps in place. The 11-inch length of pipe, when inserted into the cap and pressed firmly until it touches bottom, results in a total insulator length of 12 inches (0.31 m). Four insulators are required: one at each of the joints and one near the open end of the ring for support. It is wise to locate this insulator as far back from the end of the ring as possible because of the increasing high rf voltage that develops as the end of the ring is approached.[4] As a final measure, the bottom ends of the insulators were sealed to prevent moisture from forming on the inside surfaces. Standard PVC caps could be used here, but we found that plastic caps from 15-ounce aerosol cans fit well.

Making the Mounting Plate

The mounting plate is required to provide good mechanical and electrical connections for the grounded leg of the radiator, the coaxial feed-line connection, and the tuning mechanism. If you are using aluminum tubing, you should use an aluminum plate, and for steel tubing, a steel plate to lessen corrosion from the contacting of dissimilar metals. Dimensions for the plate are shown in Fig. 27. The important consideration here is that good, solid mechanical and electrical connections are made between the ground side at the coaxial connector, the ring base, and the tuning capacitor.

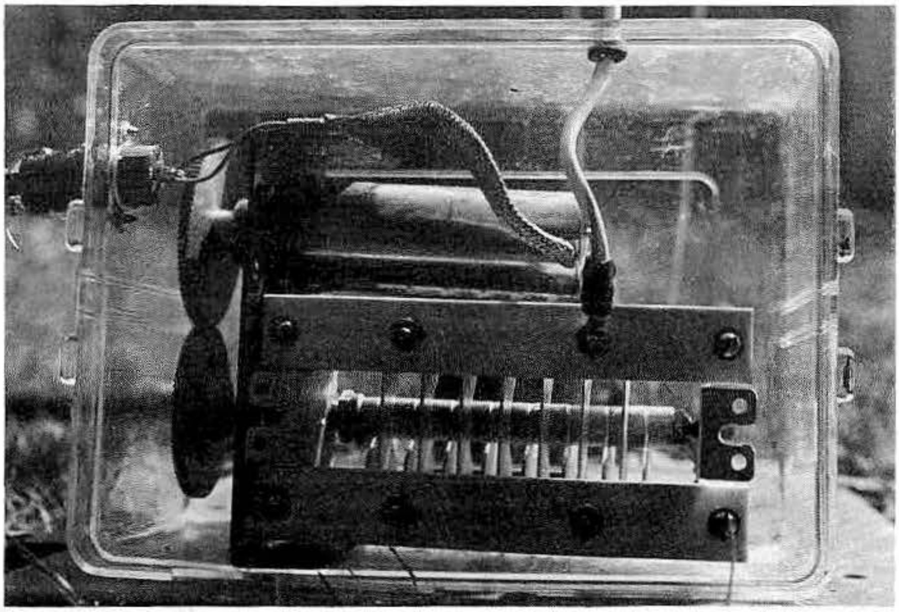
The Tuning Unit

We found that the 9-foot (2.74 m) ring resonated easily with approximately 20 pF of capacitance between the high end of the ring and the base plate or ground. A 35-pF double-spaced variable from the junk box was pressed into service here (Cardwell NG-35-DS). Any variable which will tune the system to resonance and which will not arc under full power should be satisfactory. Remember, the rf voltage at the high impedance end of this antenna can reach 20 to 30 kV with high power, so if you are using the maximum legal limit, you would do well to consider using a vacuum variable capacitor. Since we limited our power to 500 watts PEP, the double-spaced Cardwell unit was satisfactory. To provide for full band coverage, the capacitor was coupled to a reversible, slow-speed motor which enabled the antenna to be remotely tuned from the operating position. An indicated SWR of 1.1 to 1 was easily achieved over the entire 40-meter band. The motor used was a surplus item made by Globe Industries of Dayton, OH.[5] At 20 volts dc the shaft of this motor turns at about 1 rpm which is ideal for DDRR tuning. The gears used were surplus items. If you cannot obtain gears, string and pulley drive will do almost as well, or you can mount both the motor and the capacitor in line and use direct coupling. Of course, if you operate on a fixed frequency or within a 40- to 50-kHz segment of the band, you can dispense with the motor entirely and simply tune the capacitor manually. In any case, the tuning unit must be protected from the weather. We used a plastic refigerator box to house the tuning capacitor and its drive motor.

Fig. 28 shows the electrical connection for the motor. A small train transformer or power supply for toy slot-cars will work admirably as a tuning motor power source. Standard ac zip cord was used for the connection between the control unit and the motor.

Electrical Connections and the Groundplane

The connection between the open end of the ring and the tuning capacitor is made with no. 12 wire or larger. On the end of the base plate opposite the tuning unit, and directly under the ring about 8 inches (203 mm) from the grounded post, install a bracket for a coaxial connector. The connector should be oriented so that the feed line will lead away from the ring at close to 90 degrees. Install a clamp on the ring directly above the coaxial connector. Connect a lead of no. 12 or larger wire from the coaxial connector to the clamp. This wire must have a certain amount of flexibility to accommodate the movement necessary when adjusting the match. The matching point must be found by experimentation. It will be affected by the nature and quality of the groundplane over which the antenna is operating. The antenna will function over earth ground; however, in our location we found the electrical ground to be unpredictable. A groundplane surface of chicken wire (laid under the antenna and bonded to the base plate) provided a constant ground reference and improved performance. In a rooftop location sheet metal roofing should provide an excellent groundplane. A poor ground usually results in a matching point for the feed line far out along the circumference of the circle. In our installation a near-perfect match was obtained with the feed line connected to the ring about 12 inches (0.31 m) from the grounded post. During testing, when the antenna was set up on a concrete surface without the groundplane, a match was found when the feed line was connected nearly 7 feet (2.13 m) from the post!



The tuning motor, above the capacitor, couples to the capacitor shaft through the gears at left. Both the motor and the capacitor are mounted on a common bracket which attaches to the base plate by two bolts through the weatherproof housing. The lead passing upward through the grommet connects the stator of the capacitor to the open end of the ring.

As shown in photos, the compactness of the antenna is readily apparent. The groundplane is made up of three 12-foot (3.66-m) lengths of chicken wire, each 4 feet (1.22 m) wide, which are bonded along the edges at about 6-inch (152-mm) intervals. In our installation the antenna, with the groundplane, could be dismantled in about 30 minutes. If portability is not important, it is best to bond all of the joints in the tubing so that good electrical continuity is assured.

After all construction is completed, the antenna should be given a coat of primer paint to minimize rust. If it suits you, there is no reason why a final coat of enamel could not be applied.

Tuning Procedures

Once the mechanical construction is completed, the antenna should be erected in its intended operating location. Coupling to the station may be accomplished with either 52-ohm or 72-ohm coaxial cable. Tune and load the transmitter as with any antenna. While observing an SWR meter in the line, operate the tuning motor. Indication of resonance is the noticeable decrease in indicated reflected power. At this point, note the loading of the transmitter; it will probably increase markedly as antenna resonance is approached. Retune the transmitter and move the feed-point tap on the antenna for a further reduction in indicated reflected power. There is interaction between the movement at the feed tap and the resonance point; therefore, it will be necessary to operate the tuning motor each time the tap is adjusted until the lowest SWR is achieved. Don't settle for anything less than 1.1 to 1. With a good ground and proper tuning and matching, this ratio can be achieved and maintained over the entire band. Once the proper feed point has been located, the only adjustment necessary when changing frequency is retuning the antenna to resonance by means of the motor. If the antenna is to be fixed tuned, provide an insulated shaft extension of 18 inches (457 mm) or so to the tuning-capacitor shaft for manual adjustment. This not only provides insulation from the high rf voltage but also minimizes body-capacitance effects during the tuning process.

Alternatives

A number of materials other than the steel tubing used here are well suited for the ring element. Standard E.M.T. or electrical conduit would work as well with a slight increase in weight. One advantage to be gained through the use of conduit is the elimination of the flaring operation since standard couplings would serve to connect each segment of the ring to its adjacent member. Another suitable material is copper tubing. This material is superior to either exhaust pipe or conduit in terms of its conductivity characteristics. Another advantage of copper is that it is available in continuous lengths and the joints could be omitted entirely.

The 2-inch (51 mm) dimension is by no means mandatory. Smaller diameter tubing has been used with satisfactory results.[6] In fact, DDRR antennas have been fabricated with wire elements. But, if the element diameter is reduced, the antenna tunes more *sharply*. Some experimenters may wish to go in the other direction and use a larger diameter. The author recommends the use of aluminum downspout with a diameter of about 4 inches (2 mm). This material does not lend itself to bending, however, and the ring must be configured as a regular polygon of eight or more sides. Because of the large number of joints involved, welding is about the only practical means of joining the segments. Unless you are equipped to do this work yourself, the cost of welding might be prohibitive. Anyone who undertakes to make a DDRR antenna of a large element diameter will be rewarded in terms of improved performance.

Performance

Results have been quite encouraging, and it is hoped that more and more hams will equip themselves with the DDRR in the future. The antenna has proved its worth and deserves more investigation by the amateur fraternity than it has been given in the past. No intensive efforts have been made to work DX with the antenna described here: however, a low angle of radiation is conducive to DX, and this antenna demonstrates a low radiation angle. It was found that distant areas, such as the East Coast, are more easily contacted than are stations nearby. All of the results could be attributed to peculiarities of individual stations or skip conditions, but since they are charateristics which can be anticipated with high-efficiency antennas having low radiation angle, we prefer that interpretation. Besides, where else will you find an antenna for 40 meters that is small enough to fit into a corner of the backyard and not protrude above the fence; or for that matter, which could be mounted on the roof of an apartment building or even a ranch-type house and not be visible from the street?

Nearly everyone who listened to the description of this new antenna was enthusiastic. The author hopes to hear many hams on the air working with the DDRR in the near future. This material was originally presented in *QST* by W. E. English, W6WYQ.

Parts List

4 — 10-ft (3.05 m) lengths of 2-in. (51 mm) tubing, exhaust pipe, conduit or copper tubing.
1 — base plate 7-1/2 X 19 X 1/8 inches (191 X 482 X 3 mm), steel, aluminum, or copper to match tubing.
4 — PVC pipe caps for 2-inch (51 mm) pipe.
4 feet (1.22 m) of 2-inch PVC pipe.
2 clamps for 2-inch tubing.
4 — 1/4 X 4-inch (6 X 102 mm) bolts with nuts.
1 reversible motor with 1-rpm shaft output.
1 wide spaced variable capacitor. 5 to 35 pF (Millen 16550 or equiv.).
1 coaxial connector SO-239.
2 sets 2-connector plug and socket for motor control.
36 feet (10.97 m) of 4-foot (1.22 m) chicken wire or equivalent.
1 flange to attach tube to base plate.
2 — 1/2 X 1-inch (13 X 25 mm) bolts with nuts (flange mounting).
8 — 3-inch (76 mm) bonding strips no. 8 braided wire.
4 plugs 2-inch (51 mm) ID for insulator bases.

References

Hicks, "The DDRR Antenna: A New Approach to Compact Antenna Design," *CQ*, June 1964.

Horn, "The Half Wavelength DDRR Antenna," *CQ*, September 1967.

The Radio Amateur's Handbook, 46th ed., The American Radio Relay League.

Notes

[1] English, "A Practical DDRR Antenna," *73*, June 1970.

[2] Boyer, U.S. Patent Nos. RD 26196, RE 3,151,328 (All rights assigned to the Northrop Corporation.)

[3] Boyer, "Hula-Hoop Antennas: A Coming Trend?" *Electronics*, January 11, 1963.

[4] Editor's Note: Because of the danger of rf burns, in the event of accidental contact with the antenna, precautions should be taken to prevent random access to the completed installation.

[5] Globe C-5A-1106 (available from Lectronic Research Labs Inc., 75 Arch St., Philadelphia, PA 19106).

[6] See footnote 1.

Novi-Loop

A medium-size roll of wire, some insulators and a day of good antenna "puttin' up" weather can net you a Novi Loop. What will it do for you? Well, follow these instructions and get set to work 40-meter DX. Nuff said!

One of the sad facts of life for many beginners is the matter of poor antenna performance. Many enthusiastic Novices have fallen behind in their efforts to work DX because of bitter disappointment caused by poor performance in the antenna department. All too often it is suggested that a simple end-fed hunk of wire is ample for all-around Novice band operation, or that a dipole will suffice for most Novice operation. Sure, almost any kind of radiator that can be tuned to the operating frequency and marched to the impedance of the feed line and transmitter will enable the operator of a low-power station to make some contacts from time to time. It depends on how high the system is above ground, how free and clear it is of surrounding objects that can detune the radiator and absorb the energy radiated from it, and upon the condition of the band at a given time. It should stand as a firm rule, then, that any amateur who wants good results should erect the best antenna system he can, consistent with available space, finances and structural practicality. It is possible to advance beyond the plateau of simple dipoles and random-length wires in the quest for better performance, and without going to the expense and effort of erecting large directional beams such as the cubical quad or Yagi.

What will be described here can be applied to any of the high-frequency amateur bands. However, the example given relates to only the 40-meter Novice band. The antenna is a full-wave loop of wire, mounted through necessity at W1FB in a rectangular format, and matched with a simple quarter-wavelength coaxial transformer. It has given excellent performance in DX work and for making "solid" stateside contacts. Total cost for the antenna system (wire, matching transformer and insulators) is under $12, exclusive of the feed line used to connect the antenna to the rig.

Antenna Features

Full-wave, closed-loop antennas are broadband, low-Q devices. This is a handy feature because it permits the operator to move his transmitter frequency within a particular band without need to compensate for an increase in standing-wave ratio (SWR) which might otherwise occur if other types of antennas were used. (The higher the Q of an antenna, the narrower its bandwidth, even though an SWR of 1 can be obtained at some frequency within the band for which it is built.) The foregoing rules out the need for a Transmatch with the loop antenna, provided the feed method recommended here is applied.

Another interesting feature of this kind of antenna is the theoretical gain of approximately 2 dB it exhibits over a half-wave dipole. The angle of radiation from a properly erected full-wave loop is considered to be lower than that of a dipole when both are less than one-half wavelength above ground. This feature suggests the superiority of the loop in situations where significant height above ground is not a practical goal for the chap wishing to put up a 40-meter antenna.

A full-wavelength closed loop need not be square. It can be trapezoidal, rectangular, circular, or some distorted configuration in between those shapes. For best results, however, the builder should attempt to make the loop as square as possible. The more rectangular the shape, the greater the cancellation of energy in the system, and the less effective it will be. The effect is similar to that of a dipole whose effectiveness becomes impaired as the ends of the dipole are brought closer and closer together. The practical limit can be seen in the "inverted-V" antenna, where a 90-degree apex angle between the legs is the minimum value used. Angles that are less than 90 degrees cause serious cancellation of the rf energy.

The loop can be fed in the center of one of the vertical sides if vertical polarization is desired. For horizontal polarization it is necessary to feed either of the horizontal sides at the center. At the time of this writing there have been no data compiled to provide a comparison between the performance, vertical versus horizontal. Such an experiment could be interesting (and possibly productive) for the Novice.

Erecting the Antenna

Optimum directivity occurs at right angles to the plane of the loop, or in more

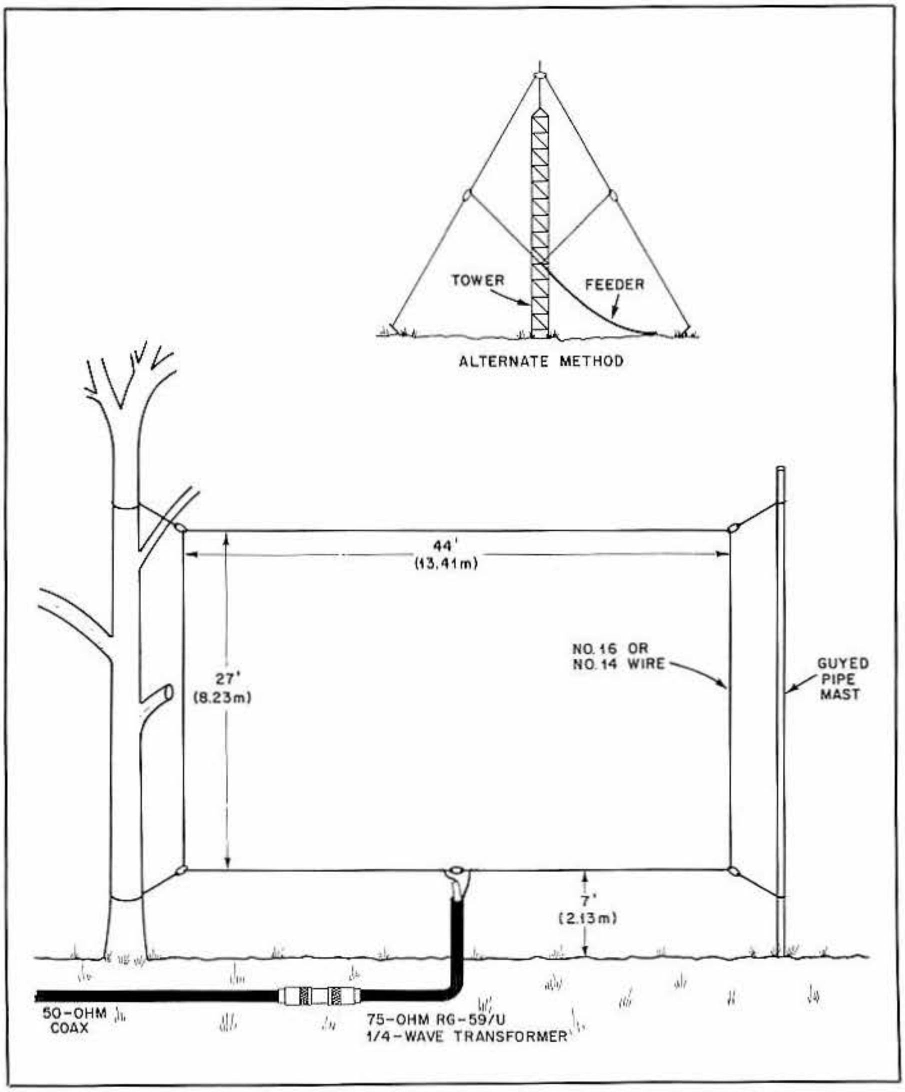


Fig. 29 — Details of the full-wave loop. The dimensions given are for operation at the low end of 40 meters (7050 kHz). The height above ground was 7 feet (2.13 m) in this instance, though improved performance should result if the builder can install the loop higher above ground without sacrificing length on the vertical sides. The inset illustrates how a single supporting structure can be used to hold the loop in a diamond-shaped configuration. Feeding the diamond at the lower tip provides radiation in the horizontal plane. Feeding the system at either side will result in vertical polarization of the radiated signal.

simple terms, broadside from the loop. Therefore, one should try to hang the system from available supports which will enable the antenna to radiate the maximum amount in some favored direction. The bidirectional pattern is maximized NE and SW at the writer's QTH. This gives good results in working Europeans and the stations "down under." Excellent signal reports have been obtained off the sides of the loop when working within the USA.

Just how the wire is erected will depend on what is available in one's yard. Trees are always handy for supporting antennas, and in many instances the house is high enough to be included in the lineup of solid objects from which to hang a radiator. If only one supporting structure is available it should be a simple matter to put up an A frame or pipe mast to use as a remaining support. (Also, tower owners see Fig. 29 inset.)

The overall length of the wire used in a loop is determined from the formula

$$\frac{1005}{\text{f (MHz)}}.$$

Hence, for operation at 7125 kHz the overall wire length will be 141 feet (42.98 m). The matching transformer, an electrical quarter wavelength of 75-ohm coax cable, can be computed by dividing 234 by the operating frequency in MHz, then multiplying that number by the velocity factor of the cable being used. Thus, for operation at 7125 kHz

$$\frac{234}{7.125\ \text{(MHz)}} = 32.84 \text{ feet}$$

If coax with solid polyethylene insulation is used, a velocity factor of 0.66 must be employed. Foam-polyethylene coax has a velocity factor of 0.80. Assuming we are to use the solid dielectric coax, RG-59/U, the length of the matching transformer becomes 32.84 (feet) × 0.66 = 21.67 feet, or 21 feet 8 inches (6.605 m). The transformer will convert the 100-ohm feed-point impedance of the loop to 50 ohms, a convenient value for connecting the system to the transmitter. The loop described here was measured with the K1TD Macromatcher[1] and found to exhibit an impedance of 110 ohms. Some inductive reactance was indicated. By removing 1 foot (0.31 m) of wire from the overall loop the reactance dropped to zero, though the antenna loaded up fine prior to the final trimming. The feed impedance at 21 MHz was also 110 ohms, but considerable inductive reactance was observed. Most certainly one could use the antenna on 15 meters with reasonable success, despite the SWR which might be present.

Results

During two weeks of testing the loop gave an excellent account of itself. It was compared with the writer's two-element short beam for 40 meters, and the results indicated that the loop was better than the beam on some occasions. At other times the beam provided better performance, or was at least equal to the loop. The differences noted were the result of band conditions and the time of day. High-angle signals can cause misleading results when comparing antennas for hf-band use. More meaningful tests can be made on ground-wave contacts, however, and several checks made between the loop and the beam indicated that radiation at right angles to the plane of the loop compared closely with that from the front of the beam. The beam is rotatable and installed 40 feet (12.19 m) above ground.

With 150 watts dc input to the transmitter PA, and operating at the low end of 40 meters (loop was cut for 7050 kHz), the first night of operation resulted in the logging of three Russian stations, two Polish ones, two Yugoslavians, one Italian station and two English ones. The lowest report was RST 549. The highest report was RST 599. Generally speaking, the loop has outperformed the beam during most long-haul contacts. Though no effort has yet been made to work South American stations (off the side of the loop), they have been heard loud and clear, as have some VK stations via long path at approximately 2300 UTC.

It is quite likely that the Novice who chooses to erect his own Novi-Loop will have a commanding signal on 40 meters. If backyard space permits, it should be a worthwhile venture. Don't forget, the formulas and guidelines given here are applicable to the other hf Novice bands as well. This material was originally presented in *QST* by Doug DeMaw, W1FB.

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[1] Hall, "The Macromatcher," *QST*, January 1972.

Chapter 5

Antenna Theory and Test Methods

In order to obtain top performance from a given style of amateur antenna, it is important to understand the basic principles of operation. Additionally, some test procedures are necessary if one is to ensure that his or her antenna is functioning at its best. This chapter contains assorted data on antenna theory, plus a number of common-sense test methods.

These reprints of popular *QST* articles were chosen for all amateurs, regardless of their technical-aptitude levels. There's something to honor in the phrase, "Learn by doing." This chapter will help to make that philosophy a reality.

Quad vs. Triband Yagi

The controversy about quads working better than Yagis, or vice versa, may never end. But, we'll bet our newest roll of RG-8/U that you'll find some interesting reading on the subject in this report.

While stationed in Japan, a sort of DX crossroads of the world, this writer had the opportunity to observe, firsthand, the excellent performance of the cubical quad in competition with the Yagi, dipoles and an assortment of other antenna systems. In pursuing this undertaking certain steps were necessary to insure than any conclusions made would be meaningful. With this in mind a play emerged.

Objectives

In the many articles written on the cubical quad, it is noteworthy that only on a few occasions have the authors been privileged to compare the quad with other types of antennas on a real-time basis, and from the same operating location. Furthermore, when such comparisons were made, the authors generally compared against some type of monoband antenna system. A casual scanning of the 10-, 15- and 20-meter phone bands would lead one to conclude that the triband Yagi enjoys a rather high position of popularity among the antennas in general use. This being the case, it appeared that a worthwhile contribution to the data already available on the Yagi and quad might be made by conducting a series of controlled comparative tests, employing the triband Yagi and the quad. The test objectives were then defined: to compare various configurations of a cubical quad antenna with a representative commercial triband Yagi; such tests to be conducted over short, medium, and long transmission paths, and to arrive at conclusions regarding the relative merits of each antenna.

Table 1

	Mod. 1	*Mod. 2*	*Mod. 3*	*Mod. 4*
Reflector Element	72'3"	70'4"	72'5"	72'5"
Driven Element	69'	70'4"	70'5"	70'5"
Director Element	—	—	—	69'1"
Spacing "A"	7'6-1/2"	8'5"	13'4"	13'
Spacing "B"	—	—	—	13'
Stub	20-30"	34-38"	—	—

Feet X 0.3048 = m.

Inches X 25.4 = mm.

Test Plan and Procedure

Every effort was made to conduct the tests in a manner which would lessen the possibility of compromising the techniques employed by either the writer or participating stations:

1) The test to be performed by establishing communications with Amateur Radio stations located throughout the world on a random and scheduled basis.

2) Amateur Radio stations volunteering to assist in this effort to be briefed on conduct of test and data desired.

3) A voice ssb transmission to be made to the participating station, identifying the first antenna used as antenna "A."

4) The voice transmission to be followed immediately by an unmodulated carrier for a period of approximately 5 seconds.

5) The antennas would be switched, and a voice transmission made identifying the antenna as "B," and the procedures above repeated.

6) Participating stations will note signal strength related to each antenna, and provide a numerical value as observed on his S meter or other indicating device. These values to be logged, and the test reinitiated with another volunteer station.

Equipment Preparation

1) Antenna heights to be as nearly identical as possible.

2) Center of antenna horizontal lobe patterns to be as nearly identical as possible when pointing the antennas toward a participating station.

3) Resonant frequency of each antenna to be matched as closely as possible.

4) Transmission lines to be matched to antennas and transmitter loading to be as nearly identical as possible with each antenna.

5) Instantaneous transfer of antennas.

6) Relative power and SWR to be monitored continuously.

7) Prior to and after each data gathering session, equipment parameters will be verified. If a significant deviation in any parameter is noted, data collected will be discarded.

Antenna performance conclusions to be based on an analysis of data derived from a minimum of 50 unmodulated-carrier observations with each antenna configuration, and supplemented with data gathered during conventional ssb QSOs.

Table 2

	Mod. 1	*Mod. 2*	*Mod. 3*	*Mod. 4*
Total Observations	50	60	60	52
Less than 2100 miles	12	2	3	3
2100 to 4800 miles	33	31	33	32
Greater than 4800 miles	5	27	24	17
Signal Difference				
More than 1 S unit better	—	—	—	—
Less than 1 S unit better	—	—	7	9
No discernible difference	1	5	51	43
Less than 1 S unit poorer	27	46	2	—
More than 1 S unit poorer	22	9	—	—

Antenna Selection

This writer had been using a four-element commercial triband Yagi (boom length 24 feet [7.32 m], and 55 feet [16.76 m] above ground) for approximately 1-1/2 years, so the properties of this antenna were fairly well established. Furthermore, in on-the-air comparisons with competitive models of triband Yagis in use by other U.S. amateurs operating from the Tokyo area, the antenna appeared representative of commercial triband antennas in general use by the amateur community. Therefore, the Yagi in use at the author's station was selected as the reference antenna.

Text material concerning quad antennas, available to the author in Japan, was reviewed. It became evident that there are almost as many variations in quad design as there are writers on the subject. After much deliberation, and many discussions with amateurs throughout the world, the decision was made to test three models of the quad (a fourth model was tested as will be noted later). Since the physical characteristics of the quad are fairly standard, only the dimensions of the elements and the spacing between them was considered. The dimensions for the three models tested were obtained from a Japanese manufacturer of cubical quads, from Orr's book, *All About Cubical Quad Antennas,*[1] and from Dr., J. E. Lindsay, Jr., W0HJ.[2]

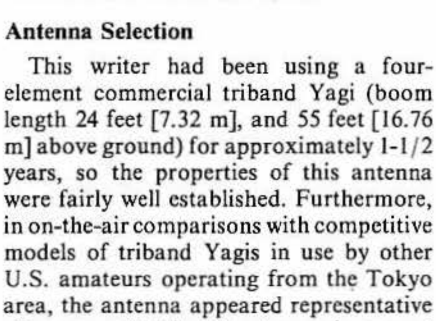


Fig. 1 — Element spacing information for Table 1.

Preliminary Testing

Several days were spent "dry running" the test plan to validate the concept, and to smooth out the operating procedures and techniques. Of particular concern was the possible time required to make a valid data-gathering observation. If data were to be reasonably accurate, the transmission path had to be stable, and the signal-strength observations must be taken on each antenna during a short period of time. The dry runs were valuable in this respect.

A problem became evident during the first day of testing. It appears that those of us who speak and understand English do not always convey the same message when using the same words. As a result it was necessary to modify the verbal format, utilizing simple sentences and placing them in a logical sequence.

It also became apparent that the test could not be conducted under all transmission-path conditions; that even under ideal conditions several observations were often necessary before a conclusive report could be compiled. It was decided to conduct the tests only on 20 meters. The operating time available to the writer favored openings on 20 meters to Europe via the long path, and to Australia, the U.S. and various islands in the Pacific. It was also decided to orient the test antennas so that the topography and obstructions seen by each antenna would be essentially the same. (Physical separation between the two antennas was in the order of one wavelength.)

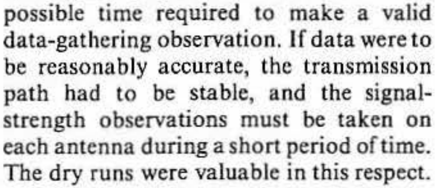


Fig. 2 — CLOSE SPACING IS FOR THE BIRDS!

Testing

Dimensions of the first quad model selected were furnished by a Japanese manufacturer of cubical-quad antennas. (see Table 1). The antenna was assembled, utilizing commercially manufactured heavy-duty hardware and fiberglass spreaders. It was tuned to a center frequency of 14,200 kHz. Testing of the first model began in November 1967 and continued for one month. The results for this period are given in Table 2.

In mid-December 1967 the first quad was replaced by a model constructed according to the formula and dimensions given in Orr's book. The results obtained with model 2 are contained in Table 2.

Construction of the third model (with wider element spacing) was carried out next. Two matching systems (Gamma and Q-section) were experimented with on this antenna. A satisfactory match could be had with either system. However, the Q-section was used for the test because it was the technique used with the previous two quad models (SWR with each antenna was never more than 1.3:1 with a difference between antennas no greater than 0.1). The results conducted with this model were most enlightening, as shown in Table 2. The model antenna was also used extensively during the first weekend of the 1968 ARRL DX Contest. Though these contacts were not used in tabulating test samplings, it is interesting to observe that openings to the U.S. (using the quad) lasted 15 to 30 minutes longer on each end of the period than with the Yagi. It is assumed that this phenomenon would also apply to each of the other quad models.

The fourth quad tested was a 3-element wide-spaced model constructed according to more dimensions furnished by W0HJ. The results of the samplings were somewhat disappointing and are given in Table 2. (Frankly, the author felt that the 3-element quad would show a substantial improvement over the Yagi in every case.) The 3-element model did appear to have a better front-to-back and front-to-side ratio than either the Yagi or the other quad models. One positive comment: The 3-element model is a monster to assemble and put up! In the author's opinion the difference in performance isn't worth the small improvement. Perhaps, on the other hand, if one accepts the 2-element model as the departure point between a simple mechanical structure and a major project, a 4-element model might be more worth the effort. However, this is purely conjecture on the part of the author.

Summary

The antenna tests indicate that:

1) One can expect to achieve the same or better results with a 2-element quad of proper dimensions than with a 3- or 4-element triband Yagi.

2) A wide-spaced quad will perform substantially better than a close-spaced quad.

3) Dollar for dollar, the quad appears to be a better investment than a Yagi.

Acknowledgements

The writer wishes to thank all of the amateurs who participated in the series of tests, particularly the VK gang, who night after night tolerated the request for observations. The support couldn't have been better, and on many occasions, upon completing a check with a particular station, several other stations would call to give their observations (which were taken during the same transmission test). This material was originally presented in *QST* by Col John H. Parrott, Jr., W4FRU.

References

[1] Orr, *All About Cubical-Quad Antennas*, Radio Publications, Wilton, CT 06897.

[2] Dimensions later published: Lindsay, "Quads and Yagis," *QST*, May 1968. (See chapter 3).

High Versus Low Antennas Performance Tests Using Identical Arrays

This section compares the performances of identical antennas mounted side-by-side at different heights, and produces some experimental evidence to support the practical importance of antenna height for most types of Amateur Radio communication.

“The higher the better” is the traditional rule of thumb for ham radio antennas. Few amateurs would disagree with this axiom, and most experienced antenna builders can recall how much better they got out after “raising the beam another 15 feet (4.57 m).” However, few empirical studies of the effect of antenna height on signal strength have been published in amateur circles.

This is unforunate, since several amateurs have studied the question methodically, including Dr. J. E. Lindsay, who has now published his definitive treatise on quads and Yagis[1] but not his excellent work in this area. And while both *The ARRL Antenna Book* and Orr's *Beam Antenna Handbook*[2] discuss the importance of antenna height in theoretical terms, neither reports the results of practical studies in the field.

With this in mind, the author set out to study the effect of height on signal strength at various distances, on several bands, and with various forms of propagation. Only amateur equipment was available for the study, but in other respects, the author strived to keep the methodology as rigorous as possible.

The Method

The two cubical quads used by the author to study the effects of antenna height on performance. The antenna at right is atop a 34-foot (10.36 m) tilt-over mast described by the author in June 1969 *QST*. The quad at left is on a 72-foot (21.95 m) tower.

The author's approach was to erect identical antennas atop two towers of different heights and obtain comparative signal reports — with some safeguards to minimize reporting errors and to assure proper statistical treatment for the resulting data. For the main tests, one tower was 72 feet (21.95 m) high (the practical maximum for the author's residential backyard at the time of the tests), while the other stood 34 feet (10.36 m) high (about the minimum usable height for DX work, according to Orr). The two towers were placed as far apart as possible without trespassing — about 50 feet (15.24 m). With this separation, no interaction was evident on any band.

A pair of 2-element cubical quads were selected for the 10-, 15- and 20-meter experiments. Each had an eight-foot (2.44 m) boom with all elements mounted concentrically on two sets of spreaders, and each antenna was fed with a single feed line (85 feet [25.9 m] of RG-8/U in both cases). This design obviously involves some compromises in element spacing and impedance matching, but both quads developed good SWR curves and front-to-back ratios when tuned. And, more important for our study, whatever compromises existed were essentially the same for both the high and low antennas.

It became apparent during the tests that many amateurs regard cubical quads as exceptional performers at low heights, but (unlike Yagis) not much better if raised higher. This popular impression is contrary to Lindsay's findings, which suggest that quads and Yagis respond quite comparably to changes in their height. Accepting Lindsay's conclusions, we assumed that our findings would be roughly the same if Yagis had been used for the primary experiments.

Table 3

Comparative Performance Data for High and Low Antennas

Band/path	*No. reports*	*No. favoring high antenna*	*No. favoring low antenna*	*No. reporting no difference*	*Mean high-antenna advantage*
20/DX	16	16	0	0	2.1 S units
20/U.S.	18	15	0	3	1.4 S units
15/DX	12	12	0	0	1.8 S units
15/U.S.	36	20	0	16	0.9 S units
15/ground-wave	12	12	0	0	2.2 S units
10/DX	8	7	0	1	1 S unit
6/ground-wave	5	5	0	0	2 S units
6/E-skip	10	2	7	1	−1.3 S units
2/ground-wave	16	16	0	0	3.3 S units

The author wanted to determine how well high and low antennas would perform not only on DX work, but on "Stateside" F-layer communications, ground-wave work, and E-skip as well. Thus, separate tabulations were kept for DX reports (i.e., those from stations more than 4000 miles away) and for reports from "Stateside" stations (i.e., F-layer reports over 1500—3000-mile paths) on each frequency band.[3] The author was careful to avoid seeking reports during anything that resembled an E-skip opening on 10, 15, and 20 meters, in the interest of studying E skip vs. antenna height separately on 6 meters.

To study the effect of height on vhf groundwave signals, the author replaced the cubical quads on the two towers with two pairs of seven-element 2-meter Yagis, each fed in phase with ratio-dipole driven elements. A move to a new home prevented the use of the same two towers for 6-meter experiments, but the author later set up two 3-element 6-meter Yagis — one atop a new 90-foot (27.43 m) tower, and the other on a 42-footer (12.8 m) — to continue the study.

On each band, the tests were conducted on ssb (except on 2 meters, where a-m was used), with an audio tone serving as a reference signal. The author switched between the high and low antennas repeatedly on each test, in an effort to counteract the effects of QSB.

This test procedure does introduce some sources of error, including the variability of hams' skills in observing the results, and the lack of receiver S-meter standardization. To cope with this kind of sampling fluctuation, the author obtained a number of reports on each band and then used t-distribution statistical methodology to evaluate the resulting data. Even with these efforts to make the study as rigorous as possible, however, the author makes no claim to finality for the results obtained. The findings on each band did prove to be statistically significant (at the 0.05 level of significance or better), but you don't "prove" things or arrive at exact parameters this way. The only claim the author makes for his results is that they suggest general trends that will probably be confirmed if this study is replicated elsewhere. There is no implication here that a 72-foot (21.95 m) high antenna produces "12-dB gain" over a 34-foot (10.36 m) -high antenna in 20-meter DX work just because the mean advantage in our tests was about two S units in this instance.

The Results

The results of these tests, summarized in the accompanying table, were interesting in several respects. With the exception of one case on 10 meters, every single DX station reported a substantially better signal from the high quad than the low one. This is thoroughly predicted in the literature, but we also found that the high quad produced a significantly stronger signal (taking the mean, or average, figure) on "Stateside" work. And on ground-wave work, the high antennas were absolutely consistent in outperforming lower ones. However, E-skip contacts proved to be another story, a point to be covered in detail later. The mean advantage of the high quad over the low quad in DX work was 2.1 S units on 20 meters, 1.8 S units on 15, and one S unit on the 10-meter band.

Since the author's linear amplifier (a commercial unit using two 3-400Zs) produces a signal gain of about two S units over the exciter alone on most S meters, it became apparent that many DX stations could not distinguish the kilowatt feeding the lower quad from the exciter "barefoot" with the higher array. The implications of this dramatic difference in signal strength for DX-contest operations are obvious: it's no wonder the "big guns" using antennas 130 feet (39.62 m) high get through the pileups quickly, with or without big linears.

On Stateside F-layer work, the pattern was less consistent, although the high array continued to hold a significant edge. While a majority of the reports still favored the high quad by one or two S units, more than a third of the stations dissented, reporting equal or virtually equal signals from the two quads. No one reported a stronger signal from the lower antenna, perhaps because of the author's effort to avoid E-ship contacts in this phase of the study. The mean advantage of the higher quad was 1.4 S units on 20-meter Stateside work, and 0.9 S unit on 15 — still a substantial advantage, but not enough to render a low antenna useless for portable work, as generations of Field Day operators can attest. In fact, the author previously described a portable quad[4] that stood only 19 feet (5.79 m) high, but nevertheless worked very well for "back-home" contacts during a long vacation. An antenna only 19 feet (5.97 m) high is clearly undesirable, but if higher antennas are not feasible, much successful hamming can still be done. (This is especially true on an occasion like Field Day, when almost everyone's antenna is low, and the few beams that are 40 [12.19 m] or more feet high seem to dominate the bands; if the competition is using a low antenna you can too!)

Ground-wave Tests

Although the plan was to study the effect of antenna height on ground-wave communication only on vhf bands, a number of stations within 100 miles volunteered reports on the hf bands. These reports were not tabulated except on 15 meters, but they consistently favored the higher array by at least two S units.

In the vhf experiments, height again proved decisive for gound-wave work. On both 2 and 6 meters, every station favored the high antenna. On two meters, the mean advantage was an amazing 3.3 S units. Surprisingly, the higher array appeared to be equally superior on contacts with San Bernardino-Riverside stations (some 30 miles from Beaumont, CA, where these tests were conducted) and on contacts into the Los Angeles basin (almost 100 miles away).[5]

After moving and acquiring the 90-foot (27.43 m) tower, the author put a single 7-element 2-meter Yagi up and took an S-meter reading on a nearby repeater with the new tower cranked down. As the tower ascended to its full height, the signal rose from S8 to 15 dB over S9 on a popular transceiver's S meter.

On 6 meters, only a few ground-wave tests were conducted, but the results were similar: Everyone favored the higher antenna substantially.

6-Meter E-Skip Tests

However, on 6-meter E skip an entirely different relationship developed: The *lower* antenna had the advantage in seven out of 10 tests during single-hop openings.[6] Only one station favored the high antenna, and the low array had a mean advantage of 1.3 S units over the high array!

Although this finding is surprising and contrary to every other test conducted, it is consistent with the one previous practical study of antenna height vs. signal strength the author could locate in ham radio literature. Working in the late 1940s, Leroy May[7] set up identical 6-meter Yagis at heights of 35 and 75 feet (10.67 and 22.8 m), and compared 350 received signals on the two arrays. He found that the low array was superior for distances below 1000 miles while the higher array began to pull ahead at distances exceeding 1100 miles.

The author made no attempt to fully replicate May's work, but all of our 6-meter E-skip experience supports him: For contacts into many major cities from greater Los Angeles, a high antenna is a handicap! Much to his chagrin, the author has frequently seen his 90-foot (27.43 m) - high Yagi outperformed on 6-meter E skip by a beam sitting 10 feet (3.05 m) above somebody's roof on a TV mast.

Conclusions and Recommendations

It is customary when reporting a study such as this to conclude by summarizing the findings and making some recommendations. The conclusion here must be that, for every application except E-skip work, there are worthwhile advantages of having an antenna at least 70 feet (21.34 m) high. This height advantage is most pronounced on ground-wave and long-haul DX work.

The only logical recommendation we can make, then, is that all hams should own towers 70 feet (21.34 m) high. May all of the XYLs, frightened neighbors, bill collectors, and zoning-conscious city officials of the world forgive us!

Alternately, maybe we should suggest that all hams (except the author) use 35-foot (10.67 m) towers to give the author a better chance in DX contests. Or better yet, how about an antenna-height multiplier for the DX contests? Let's see, that's 1.5 if your antenna is below 75 feet (22.86 m), 2.0 if it's below 40 feet (12.19 m), and 3.0 if you bury it in the ground . . . This material was originally presented in *QST* by Wayne E. Overbeck, N6NB.

References

[1] Lindsay, "Quads and Yagis," *QST*, May 1968 (See chapter 3).

[2] Orr, William I., *Beam Antenna Handbook*, 3rd Edition.

[3] No 10-meter "Stateside" tests are reported because the muf was too low for reliable F-layer work across the U.S. when these tests were run.

[4] Overbeck, "The 20-Minute Portable Quad," *QST*, May 1967.

[5] On the hf bands, it is normally assumed that a high antenna has a greater advantage over a low antenna on long-haul DX than it does on shorter paths, but the opposite may well be true for vhf ground-wave work. This is suggested in the *ARRL VHF Manual*, (1st Edition, pages 24,25). Thus, one would expect that an increase in height would result in greater improvement in signals over the 30-mile path than over the 100-mile path.

[6] At the time of the 6-meter tests, E skip was barely "in season." The author is continuing this study during seasons of more frequent E-skip openings.

[7] May, "Some Practical Results on the Question of Antenna Height," *CQ*, April 1953.

Limited-Space Antennas and Methods Of Coupling

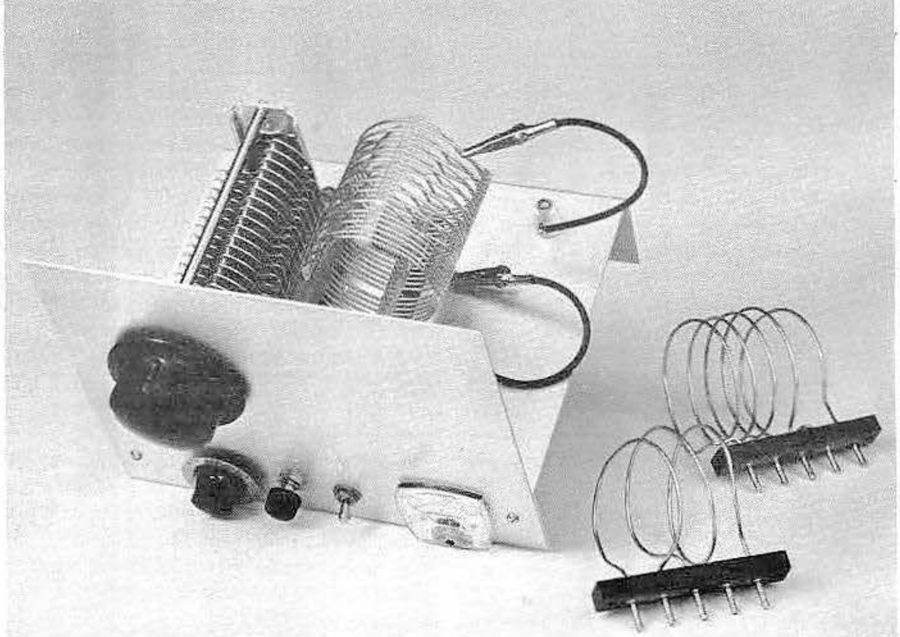
When short, random-length wire antennas prove disappointing, chances are the installer didn't follow a few basic rules for good performance. These tips should lead the way to better results with "randoms."

One very popular type of antenna, probably because of its simplicity, is a wire of either a predetermined or random length, fed at one end. It is common procedure among amateurs these days to refer to such an antenna as a "long wire." Actually, this term is usually incorrect because, by definition, a long-wire antenna is a wire that is several wavelengths long at the operating frequency. But no matter what you call it, the end-fed wire can be a very simple antenna to put up and use, if certain steps are taken.

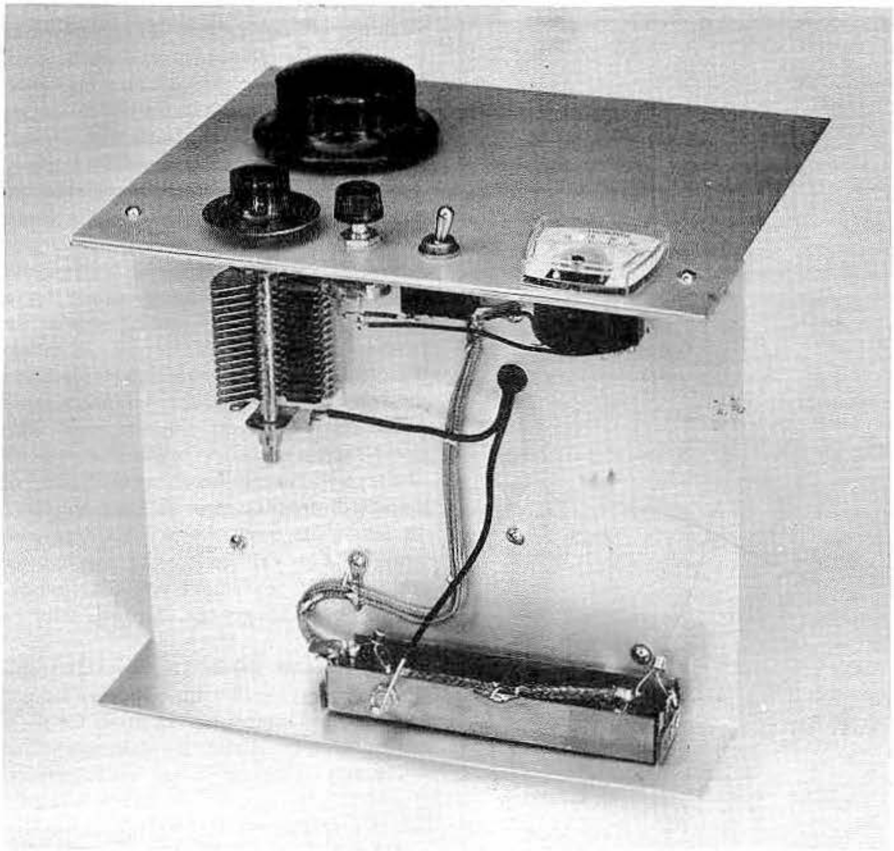
Transmitter Loads

Nearly all transmitters described these days are designed to work into 50- to 70-ohm loads, with little thought given to any load that departs very far from these figures. If the load is something different than the above figure it may be impossible to get the amplifier in a transmitter to load up. In order for the final amplifier stage to operate at its best efficiency, the load (the antenna system) must be within the design range of the amplifier.

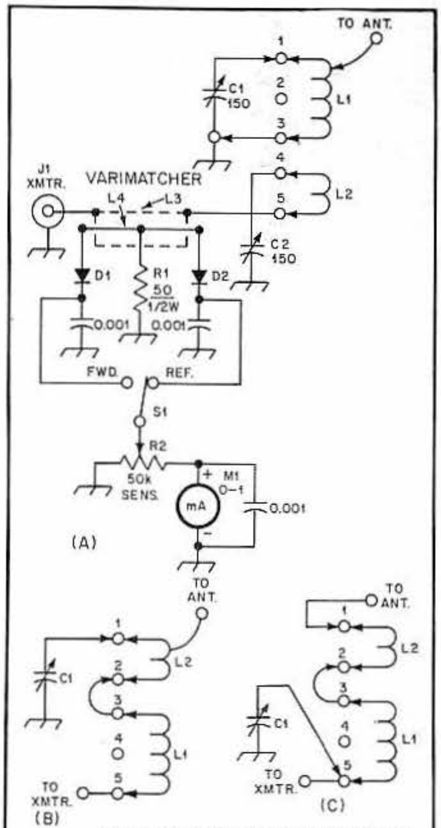
An end-fed wire may present a load of 50 to 70 ohms, but if it does it will be a case of pure luck on the part of the user — and what's more important, that load won't stay the same across a band. In other



The completed transmatch with the 80/40-meter coil plugged in. At the rear is the 20-meter coil and the 10/15-meter unit is to the front. In regular operation, the antenna would be attached to the standoff insulator at the top rear of the chassis. The clip lead visible below the coil is the one attached to the jack bar.



The wiring below deck. At the rear of the chassis is the Varimatcher section. C2 is at the left front of the chassis.



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF) ; OTHERS ARE IN PICOFARADS (pF OR μμF); RESISTANCES ARE IN OHMS ; k = 1 000, M = 1 000 000.

C2 — 150-pF variable (Millen 19140 or similar).
D1, D2 — 1N34A germanium diode.
J1 — Coax chassis fitting, type SO-239.
L1, L2 — See Fig. 7.
L3, L4 — See Fig. 6.
C1 — 150-pF variable, (air gap 0.077 inch [2 mm] or larger for high power, Millen 12515 or similar; air gap 0.040 inch [1 mm] for low power, Millen 19140W or similar).
M1 — 0-1 milliammeter (more sensitive meter can be used).
R1 — 50-ohms, 1/2-watt carbon or composition, not wire-wound.
R2 — 50 kΩ control, linear taper.
S1 — Single-pole, single-throw toggle switch.

Fig. 4 — Circuit diagram of the Transmatch and Varimatcher. All 0.001-μF capacitors are disk ceramic.

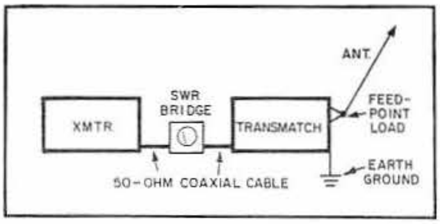


Fig. 3 — This block diagram shows the set-up for using a Transmatch. Not shown is an antenna relay which normally would be inserted in the coaxial line. If a low-pass filter is used, it should be the last item in the line before the Transmatch.

words, the antenna will present a 50- to 70-ohm load for only a very limited frequency range. Once we QSY the load may change to where it is no longer within the tuning range of the amplifier. Our problem boils down to having the transmitter *always* see a load of 50 to 70 ohms, regardless of the band or frequency in use. This in turn means we must make the antenna system look like a 50- to 70-ohm load, no matter which band we use it on.

The Transmatch, an Adjustable RF Transformer

Let's make one point clear about end-fed wires, or any antenna, for that matter: There is no way of predicting what the feed-point impedance (load) will be before making and installing the antenna. We can come close, but there are many factors that get into the act to determine what the impedance will be. The antenna's height, its proximity to nearby objects, its length, and the antenna's relation to earth ground are just a few of the factors. If we don't know what the feed-point impedance is, how can we make the transmitter always work into a 50-ohm load? The easiest way is to insert a Transmatch between the transmitter and the feed point. A Transmatch is simply an adjustable rf transformer that takes our unknown feed-point load and converts it to a desired load, 50 ohms in the case shown in Fig. 3.

Note in Fig. 3 that we show a random-length antenna and an earth ground connection. In this case, our unknown load exists between the end of the antenna and ground. On the transmitter side of the Transmatch we have 50-ohm coaxial cable and inserted in this cable is a 50-ohm reflectometer or SWR (standing-wave-ratio) bridge. The reflectometer is simply a measuring instrument that tells us when our Transmatch is properly adjusted to convert our unknown load to a 50-ohm load. If the Transmatch has adequate matching range, we can convert any feed-point load to 50 ohms. And this means that we can take any random length wire and make a working antenna out of it for any amateur band or frequency. There are some practical limits as to how short a wire we can use, but actually the antenna can be quite short in relation to a wavelength and still work.

Limited-Space Antennas

Many hams live in apartments or locations where it is impossible to put up an "antenna farm" or even a half-wave dipole for 80 or 40 meters. Random-length wires are sometimes the best bet in these circumstances. For hams who live under such conditions there are some general rules that can be followed for best performance. If possible, always get the antenna up on the roof. If not, get the antenna as high as possible. Make the wire as long as possible, even if it has to go around corners. Don't overlook existing antenna possibilities, such as rain gutters or roof flashing. In a moment we are going to describe a Transmatch that can be used to couple practically any wire or metal structure to the transmitter, including rain gutters.

If it is impossible to get an outdoor antenna up (and don't overlook "invisible" antennas[1]). an indoor antenna will work, but not as well as an outdoor one. With the Transmatch to be described, you can run a wire around the ceiling molding and couple the wire to the rig, maintaining that 50-ohm load we mentioned earlier. When you hear hams talking about loading up the bed spring, don't laugh — many a ham has made contacts that way. All you need is some method of coupling the bed spring to the rig; that's what our Transmatch will do.

The Transmatch

Shown in Fig. 4 is the circuit for a Transmatch that will do the job we've been talking about. This unit will match practically any wire to our 50-ohm rigs on any band from 80 through 10 meters. Depending on which capacitor plate spacing you use for C1 the Transmatch can be used for Novice powers or up to the legal limit of 1 kW. Actually, the closer-spaced capacitor will handle 200 watts or so. The same type coil stock is used for either power level, high or low.

Also included in the Transmatch shown in Fig. 4 and the photographs is an SWR bridge. This is a necessary item in order to know when the Transmatch is correctly adjusted. If you already have a Monimatch or reflectometer, the unit described can be eliminated from the Transmatch.

With the random-wire antenna we'll be dealing with various loads, depending on the frequency and band in use. Shown in Fig. 5 are the three basic circuit configurations used with the Transmatch. The circuit can be changed to conform with type A, B, or C by reversing the plug-in coil in the jack bar or by changing the capacitor C1 from the output side of the L configuration, as in B, to the input side, as in C. The capacitor is changed by means of a clip lead connected to the stator.

Some loads may require the circuit setup of A. In this configuration, a link-coupled parallel-tuned circuit is used, the antenna being tapped onto L1.

Construction Details

The chassis used to hold the parts is 2 × 7 × 9 inches (51 mm × 178 mm × 229 mm) and the panel measures 7 × 9 inches (178 mm × 229 mm). Any chassis large enough to hold the parts can be used. C1 and the jack bar for the plug-in coils are mounted on top the chassis, and the Varimatcher reflectometer and C2 are mounted below the chassis top. The remaining components are mounted on the chassis front.

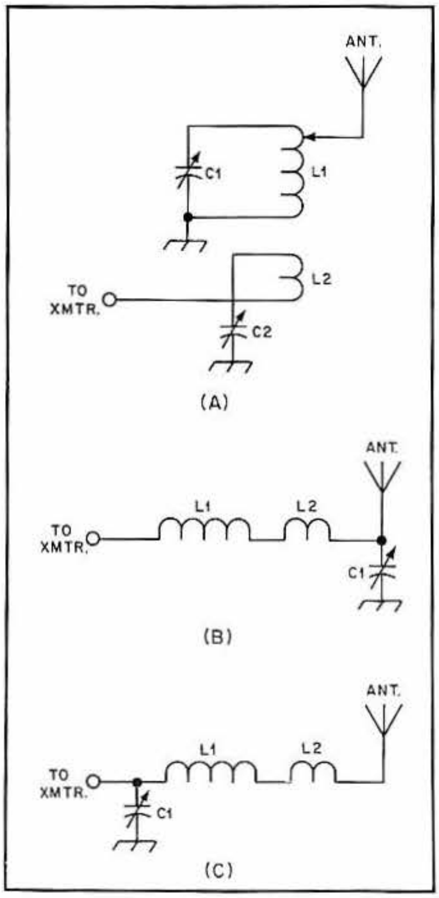


Fig. 5 — Three possible configurations with the Transmatch as described in the text. To set up types B or C the plug-in coil is reversed in the jack bar and terminal no. 3 of the jack is clipped to terminal no. 2.

A 4-inch (102 mm) length of RG-58/U coaxial cable is used for the pickup and conductor sections of the SWR bridge. Details for making this section are given in Fig. 6. Study these details and the photograph of the bottom view carefully before starting construction. The black outer covering of the coax is removed, leaving the braid and inner conductor with its insulation. The outer braid will be L3 and the inner conductor L4. You'll notice that there is an open area at the center of the coax braid. This is to allow room for the connection of one end of the 50-ohm resistor to the center of the inner part of the coaxial line. Use a probe or pointed instrument to open up the area in the braid and then carefully tin the edges of the opening with solder so as to prevent any of the hair-like wires from shorting to the resistor lead or inner conductor. The ends of the braid can be wrapped with a few turns of solid wire and tinned. The wire ends will provide a support for the connection to the feed-through terminal and the inner pin of J1.

The metal trough that houses the bridge section is made from a piece of copper flashing, although tin or aluminum could be used. It is a good idea to drill the holes for J1 and the feed-through bushing before bending up the trough into a U. Also, when soldering the leads for the diodes, D1 and D2, use a heat sink between the body of diode and the point being soldered, because too much heat can ruin the diode.

Using the Transmatch

In making the antenna, shoot for a length of at least 1/4 wavelength at the lowest operating frequency. In other words, if you plan on working 80 meters as the lowest band, then the antenna should be 60 feet (18.29 m) long, at least. This doesn't mean that shorter wires won't work — they will, but not nearly as well. A lot of hams will say they can't get up a length of 60 feet! The wire doesn't *have* to run straight. You can go around corners, up and down, or what have you. The important point is to get up as much wire as possible.

By the same token, many hams think (mistakenly) that they have to have a good earth ground connection in order for their station to work. It's fine if you have one but if you don't, forget it. If you have access to a water pipe or other earth ground connection make a connection to the rig and the Transmatch, but if you can't, don't worry. The antenna will still work.

With the antenna connected and the rig on the desired frequency, feed enough power through the system to get at least a half-scale reading on the Varimatcher meter, and have the Transmatch set up as in (A). Tap the antenna onto the first turn of the coil L1 at the "hot" end, or end opposite the ground. Incidentally, always turn the rig off when making any adjust-

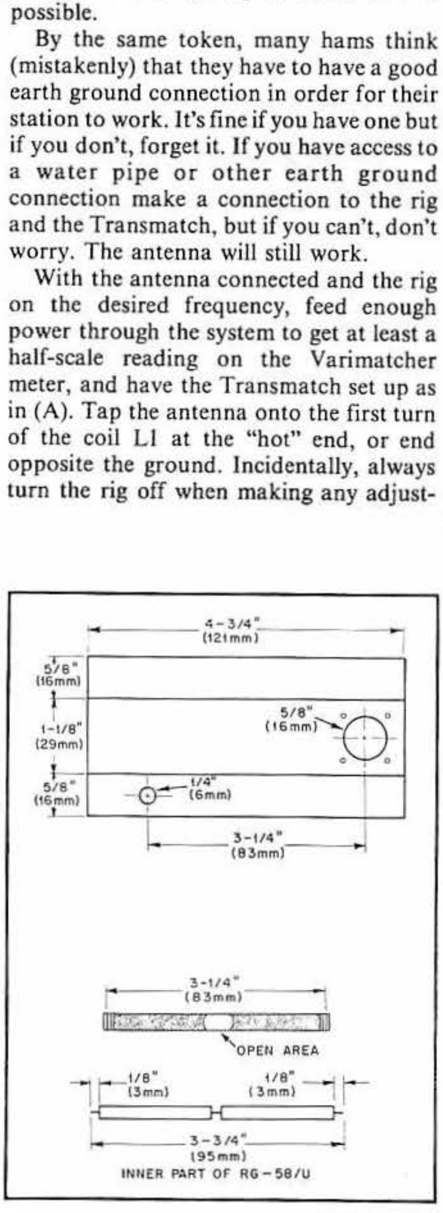


Fig. 6 — Constructional details of the Varimatcher bridge section. The braided portion of the coax is L3 and the inner portion is L4.

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[1] Any wire that is no. 28 or smaller is practically impossible to see when strung up as an antenna. Many hams use "invisible" antennas to prevent a touchy landlord situation.

ments on the Transmatch. There may not be any dc voltages present but some very, very high rf voltages can be developed on the Transmatch coils and can cause a nasty rf burn.

With the antenna tapped on near the hot end of L1 switch S1 to read reflected power and adjust C1 and C2 for a dip or minimum reading. If you cannot get the reflected reading down to zero, or close to it, turn off the power and move the antenna tap closer to the ground end of the coil. You'll eventually find a tap point that will give a reading of zero in the reflected position versus full scale in the forward position of S1. If you find that the tap point on L1 is very close, say within 25 percent, to the ground end, you may want to try configuration B or C.

In eight of these configurations, start at the antenna end of the coil and, using another short clip lead, short out turns or portions of turns as you move the antenna tap towards the transmitter end of the circuit. In other words, the antenna is always on the end of the coil, but you may have some of the coil shorted out in order to get a match as indicated by M1.

Once you get a match for any given band, make a chart of the taps and so forth so you can return to the setup when you change bands.

The main reason for using configurations B and C is that if the antenna is tapped near ground on L1 in configuration A, extremely high rf voltages can develop across C1 even with Novice powers. We don't recommend playing around with "arcs" from coils but it might be wise to prove to yourself just how much voltage can be developed. With the antenna tapped near the ground end of L1, take a pencil and hold it by the wood, not at the eraser end but in the center. With the key closed and the rig loaded up to about 75 watts, touch the lead end of the pencil to the stator of C1. You'll quickly see why caution is necessary. Such an arc can make a very nasty and painful burn.

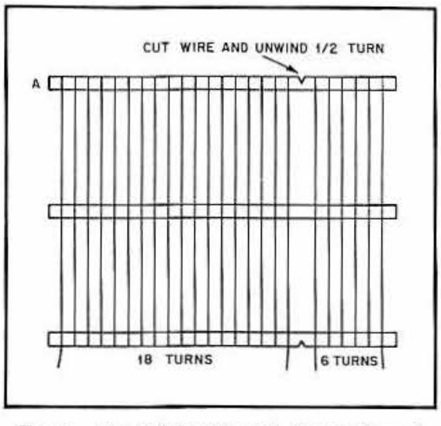


Fig. 7 — The 80/40-meter coil. To use the coil on 40 meters, short out 10 turns, counting from the "A" end of the coil. Shorting clips should be copper and the shorting leads should be insulated. Coil stock is no. 14 wire, 8 turns per inch (25 mm), 2-1/2 inches (64 mm) in diameter (Air Dux 2008T, B & W 3906-1, or Polycoils 1775).
The 20-meter coil consists of 4 turns of no. 12 solid wire, 2-1/2 inches in diameter, with the turns spaced so that L1 is 1-1/2 inches (38 mm) long. L2 is one turn of no. 12, same diameter as L1, spaced 1/2 inch (13 mm) from the end of L1. The 15/10-meter L1 coil is 2 turns of no. 12 solid wire, 2-1/2 inches (64 mm) in diameter, turns spaced to cover 1-1/2 inches (38 mm). L2 is a single turn, same diameter as L1, spaced 1/2 inch (13 mm) from L1.
All coils are mounted on Millen type 40305 plugs and the socket (jack bar) is a Millen 41305. See G. R. Whitehouse ads in *QST*.

If you want to try using antennas that are *very* short for the frequency, such as 10 feet (3.05 m) long on 80 meters (similar to a mobile whip) certain additional steps may be required to obtain a match with the Transmatch. When you make the coil for 80 and 40 meters you'll have some coil stock left over. With very short antennas, this can be used as a "loading" coil. Connect the antenna to one end of the coil and connect the other end to the antenna terminal on the Transmatch. Then go through the tune-up procedure. You may have to use a clip lead to short out turns on the coil but you'll find a setup that will permit matching with the Transmatch. Again, avoid coming in contact with the series loading coil because very high rf voltages can develop in such a setup.

Some beginners may not be aware of it, but a fluorescent lamp or neon bulb will light up when in an rf field, if the rf voltage is high enough. If you have a fluorescent lamp (a burned-out one is OK), the lamp can be laid along the antenna wire where it leaves the Transmatch. This makes a good output indicator, showing when power is flowing in the antenna. This material was originally presented in *QST* by Lewis G. McCoy, W1ICP.

Off-Center-Loaded Dipole Antennas

So you can't manage a buried radial system on your city lot, eh? Then why not scrap those plans for a vertical antenna and try K1TD's version of a short dipole? Here are the design tips you need.

In these times when much of our amateur population lives in urban areas, the subject of shortened antennas for the lower frequency amateur bands is a very popular one. Physically short ground-mounted vertical antennas with lumped-constant loading to make them resonant can be quite efficient radiators, if a good radial system has been installed. This has certainly been evidenced in Sevick's series of *QST* articles.[1] To many amateurs, however, the "hitch" in constructing such a system is the installation of a good radial system. It must be admitted that for the "top" amateur bands, 160 and 80/75 meters, an efficient system of buried radials requires a sizable amount of real estate, even for a physically short radiator. On the average city-size lot, 50 or 75 by 120 to 150 feet (15.24 - 22.86 m by 36.58 - 45.72 m), it's almost impossible to install a highly efficient radial system for 80/75 meters, much less for 160 meters, when structures like a house and perhaps a separate garage exist. Or to some amateurs, just the thought of burying hundreds or maybe thousands of feet of wire is enough to turn off any enthusiasm for the project.

What's the alternative? A dipole type of antenna with lunped-constant loading. At modest heights, 30 or 40 feet (9.14 or 12.19 m), such an antenna will prove to be quite satisfactory if it is physically longer than about 0.2 wavelength. Shorter lengths may also be used, at reduced efficiency. Such an antenna can be fed directly with 50-ohm coaxial line, and it can be operated with no earth ground. (Of course the chassis of the transmitter and/or receiver should be grounded adequately for protection against shock hazard.)

Nearly all of us are familiar with the concept behind the use of inductive loading. A vertical antenna which is shorter than a quarter wave (or a dipole antenna which is

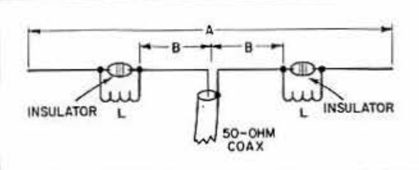


Fig. 8 — A dipole antenna lengthened electrically with off-center loading coils. For a fixed dimension A, greater efficiency will be realized with greater distance B, but as B is increased, L must be larger in value to maintain resonance.

(Eq. 1):

$$L_{\mu H} = \frac{10^6}{68\pi^2 f^2} \left\{ \frac{\left[\ln \frac{24\left(\frac{234}{f} - B\right)}{D} - 1\right] \left[\left(1 - \frac{fB}{234}\right)^2 - 1\right]}{\frac{234}{f} - B} - \frac{\left[\ln \frac{\left(24\,\frac{A}{2} - B\right)}{D} - 1\right] \left[\left(\frac{\frac{fA}{2} - fB}{234}\right)^2 - 1\right]}{\frac{A}{2} - B} \right\}$$

where

$L_{\mu H}$ = inductance required for resonance
ln = natural log
f = frequency, MHz
A = overall antenna length, feet
B = distance from center to each loading coil, feet
D = diameter of radiator, inches

shorter than a half wave) will exhibit capacitive reactance at its base (or center) feed point. To cancel such capacitive reactance, a coil having the proper inductive reactance may be connected in series with the base feed point of the vertical. The same result will be obtained through the use of two such coils for a dipole, one coil connected in series with each half. It is not necessary for the inductor to be installed at the feed point, however. In fact greater radiating efficiency results through improved current distribution if the inductor is located along the radiator some distance away from the low-impedance feed point, *viz,* in the manner of a center-loaded mobile whip antenna. Fig. 8 shows this concept extended to a dipole element, with off-center loading. The inductors resonate the antenna to the operating frequency, but do little actual radiating themselves. (This is in contrast to helically wound or continuously loaded elements, where a long thin inductor is the radiator as well as the loading element.)

In the antenna represented by Fig. 8, there are many variable factors to be considered when a practical antenna for a given frequency is being constructed. Of primary consideration from an efficiency standpoint is the overall length, shown as dimension A. Another consideration for efficiency is the distance of the coils from center, dimension B. The longer the overall length (A), up to a half wave, and the farther the loading coils are placed from the center (B), the greater is the efficiency of the antenna. However, the greater is distance B (for a fixed overall antenna size), the larger the inductors must be to maintain resonance. Theoretically, if the coils were placed at the outer ends of the dipole, they should be infinite in value to maintain resonance. Capacitive loading of the ends, either through proximity of the antenna to other objects or through the addition of capacitance hats, will reduce this requirement to a more practical value.

What Inductance Values?

As a matter of personal interest, this writer has been doing experimental work for a number of years with off-center-loaded antennas. One big drawback to such experimentation was the ever-present need for a large amount of cut-and-try work to arrive at resonance whenever a new set of dimensions was to be used. Probably the number of pruned-off turns from coil stock from such experiments, if straightened out and soldered end to end, would make up several full-sized half-wave antennas for the 160-meter band. Therefore, most of the writer's work of late in this area has been in going through paperwork exercises, looking for a way whereby at least "ball-park" values of inductance needed for a particular system could be calculated.

The equation contained in the Mobile chapter of *The ARRL Antenna Book* for determining the capacitance of a vertical antenna shorter than a quarter wavelength looked promising in early computations, and, indeed, it became the basis for the calculation procedure which finally resulted. This procedure has been found to produce results much closer than mere "ball-park" values for the necessary inductance — for wire antennas "in the clear" at moderate heights, the final inductance values found by cut-and-try pruning for lowest SWR at the desired frequency have been so close to the value from calculations that a laboratory bridge was necessary to measure the difference. The results are equally good for elements using tubing. Once the needed inductance value is determined by calculations, it is generally found sufficient to obtain coil dimensions from an ARRL L/C/F Calculator (see LaPlaca[2]) or by equation. Any significant pruning which has been found necessary could always be attributed to objects in proximity to the ends of the antenna.

The complete set of calculations is expressed in the mathematical relationship as Eq. 1, presented here primarily for mathematics buffs or those having access to electronic computers. This equation yields the inductance required, in microhenrys, for single-band resonance of a shortened antenna of a particular physical size at a given frequency, for a specific position of the loading coils from the center of the antenna. To spare the reader the task of performing some rather tedious calculations, Fig. 9 has been prepared from Eq. 1. The curves of the chart have been normalized, and may be used for any frequency of resonance. The chart is based on a half-wavelength/diameter ratio of the radiator of approximately 24,000. (This corresponds to no. 14 wire on 80 meters or no. 8 wire on 160 meters.) For "thinner" conductors, the required inductance will be somewhat greater than that determined from Fig. 9, and less inductance will be required for "thicker" conductors.

The use of the chart is as follows: At the intersection of the appropriate curve from the body for dimension A and the proper value for the coil position from the horizontal scale at the bottom of the chart, read the required inductive reactance for resonance from the scale at the left. Dimensions A and B are shown in Fig. 8, and for use with the chart are expressed as percentages. Dimension A is taken as percent length of the shortened antenna with respect to the length of a resonant half-wave dipole of the same conductor material. Dimension B is taken as the percent of coil distance from the feed point to the end of the shortened antenna. For example, resonating an antenna which is 50 percent or half the size of a half-wave dipole (one-quarter wavelength overall), with loading coils positioned midway between the feed point and each end (50 percent out), would require loading coils having an inductive reactance of approximately 950 ohms at the operating frequency. If the antenna is hung "in the clear," and if the length/diameter ratio of the conductor is near 24,000, inductance values as determined from the chart will be very close to actual values required. (Eq. 1 above takes the diameter of the radiator into account, and thus may be used for any length/diameter ratio.) For practical

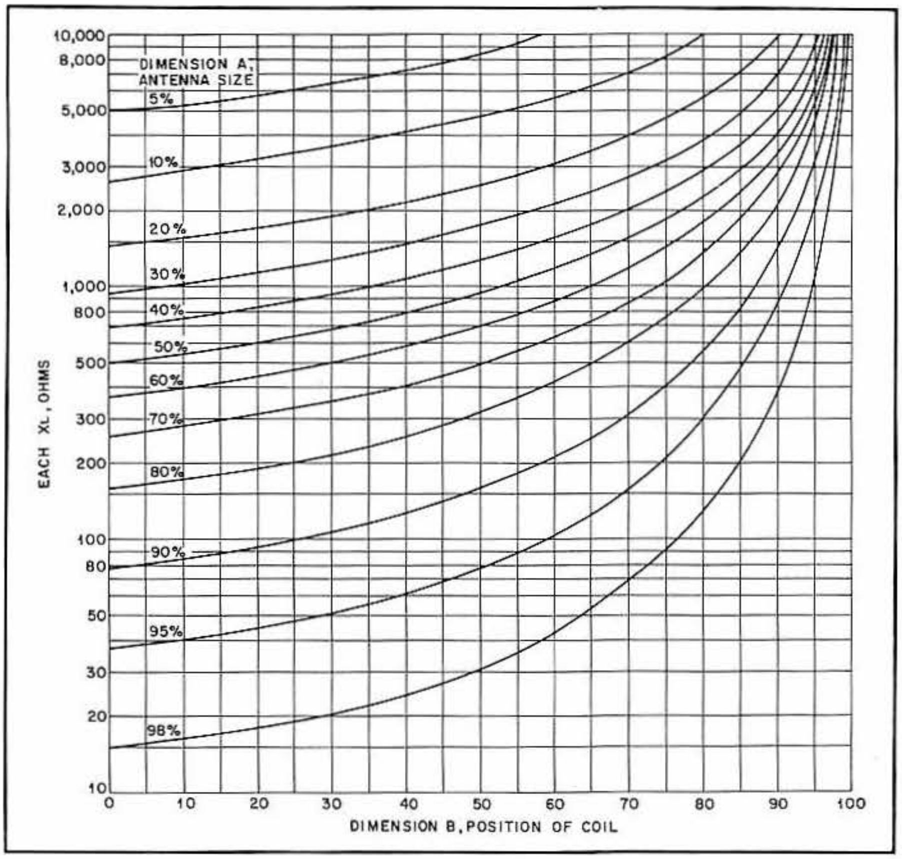


Fig. 9 — A chart for determining approximate inductance values for off-center-loaded dipoles. At the intersection of the appropriate curve from the body of the chart for dimension A and the proper value for the coil position from the horizontal scale at the bottom of the chart, read the required inductive reactance for resonance from the scale at left. See Fig. 8 regarding dimensions A and B.

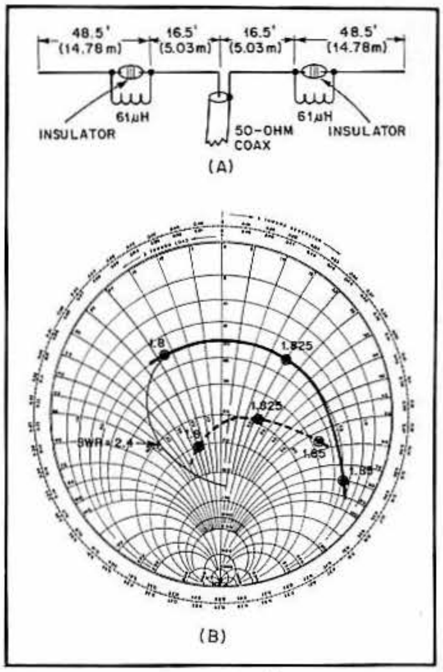


Fig. 10 — At A, an 80-meter dipole loaded for 160-meter operation. The inductors are 37 turns of coil stock having a 3-inch (76 mm) dia and 10 turns per inch (25 mm) (B & W 3035). At B, the impedance plot of this antenna installed at a height of 50 feet (15.24 m) (solid curve), and the plot of a 160-meter half-wave dipole (broken curve).

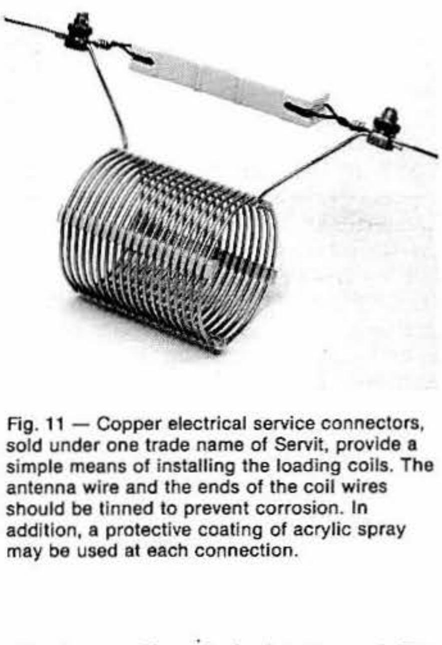


Fig. 11 — Copper electrical service connectors, sold under one trade name of Servit, provide a simple means of installing the loading coils. The antenna wire and the ends of the coil wires should be tinned to prevent corrosion. In addition, a protective coating of acrylic spray may be used at each connection.

purposes, dimension B may be taken as that distance from the center of the feed-point insulator to the inside eye of the loading-coil insulator, and dimension A as the eye-to-eye distance inside the end insulators (which are not drawn in Fig. 8).

Proximity of surrounding objects in individual installations may require some pruning of the coils, and the exact amount of final inductance required should be determined experimentally. If the antenna is hung in inverted-V style, with the ends brought near the earth, the required inductance will almost always be somewhat less than that determined from the chart or equation. A grid-dip meter, Macromatcher (see Hall and Kaufmann[3]), or SWR indicator may be used during the final adjustment procedure.

Practical Antennas

Although one might erect an inductively loaded antenna that is cut for a single amateur band, it is possible to use the antenna itself for two, three or more bands of operation, if provision is made to lower the antenna for band changes. A simple rope halyard and pulley arrangement at one of the supports will do the trick. Fig. 10A shows a three-band antenna of this nature, for 160, 80 and 20 meters. If the insulators shown are left open, with nothing bridging them, the antenna is a simple half-wave dipole cut for 14.18 MHz. (The 48.5-foot [14.78 m] lengths act merely as support wires, and have negligible effect on operation of the antenna.) If the insulators are bridged with short lengths of antenna wire, the antenna becomes a center-fed 80-meter dipole, resonant at about 3.6 MHz. For 160-meter operation the 20-meter insulators may be bridged with loading coils to resonate the antenna at 1.8 MHz, as shown in Fig. 10A. Burndy or other manufacturers' "Servit" type of electrical connectors may be used for ease in making band changes quickly, as shown in Fig. 11.

The calculation procedure for determining loading-coil values for the antenna of Fig. 10A, using the chart of Fig. 9, goes like this. If operation is desired on 1.8 MHz, the length of a full-sized half-wave dipole is found from the relationship 468/f to be 260 feet (79.25 m). The 130-foot (39.62 m) length of Fig. 10A represents 50 percent of this size, meaning that the dimension-A curve marked "50 percent" in Fig. 9 is to be used. The position of the coils is $16.5/(16.5 + 48.5) \times 100$, or 25 percent of the distance out from center, dimension B. From the intersection of 25 (horizontal scale at bottom) and the 50 percent curve, the required inductive reactance is read from the scale at the left of Fig. 9 to be 650 ohms. The inductance, L, is $650/2\pi f$ or 57.5 microhenrys, if no. 8 wire is to be used. For smaller diameter wire, the inductance should be somewhat larger. (Calculations from Eq. 1 for no. 12 wire indicate the required inductance is 60.99 μH.)

The radiation resistance of a shortened antenna loaded to resonance is less than that of a full-sized antenna. Further, the shortened antenna is "sharper," meaning that the change in reactance versus frequency is greater. In other words, the shortened antenna acts as a tuned circuit having a higher Q than a full-sized antenna.

To check these characteristics, the line input impedances for the antenna of Fig. 10A were measured with a laboratory bridge, and the electrical line length at the measurement frequency was then taken into account to determine the impedance at the antenna feed point. The antenna was constructed of no. 12 wire and hung at a height of 50 feet (15.24 m) as a "flat-top" radiator.

The solid curve of Fig. 10B is a plot of the feed-point impedance versus frequency for this antenna. The plot on Smith Chart coordinates is more meaningful than a simple SWR-vs.-frequency curve because the magnitudes of the resistive and reactive components are shown, as well as the sign of the reactance. (Capacitive reactance is negative, plotted to the left of the vertical center line, and inductive reactance is positive, plotted to the right.) In this presentation, a 50-ohm nonreactive impedance will appear at the exact center of the chart. The SWR in 50-ohm line for a given frequency may be determined by first noting the distance from the center of the chart to the particular impedance plot on the curve, and next measuring this same distance down the vertical center line from chart center (a drawing compass is helpful for this task), and finally dividing 50 into the value read at that point on the center line. For example, the SWR at 1.8 MHz equals 120/50 or 2.4, as indicated by the segment of the 2.4 SWR circle in Fig. 10 B. It may be seen that resonance (zero reactance) occurs at approximately 1810 kHz, where the resistance is about 22 ohms. The SWR at resonance is 2.33:1, and climbs to 3:1 at 1825 kHz. At 1850 kHz, the SWR is 10:1. Without any matching provisions the antenna is relatively sharp, as mentioned earlier. If one sets the usable bandwidth as the frequency range where the SWR is 3:1 or less, it is approximately 35 kHz, or 1.9 percent of the resonant frequency. As far as efficiency is concerned, ohmic losses are low, and the antenna is a good performer on 160 meters. Because of its horizontal polarization, it has proved to be most effective at night, and stations several hundred miles away have been worked with S 9 reports received for the 50-watt signal.

For a comparison of impedances, the broken curve of Fig. 10B is a plot of measured impedances of a full-size half-wave dipole, 260 feet (79.25 m) long overall, hung in place of the shortened antenna. From this curve it may be seen that resonance occurs at 1810 kHz, where the resistance is 59 ohms. The 3:1-SWR bandwidth for the half-wave antenna is in the order of 60 kHz, or 3.3 percent of the resonant frequency. It is interesting to note on this curve that the SWR at resonance is 1.18:1, and that it is a somewhat lower value, 1.15:1, at a frequency a few kilohertz above resonance. (Measurements were made every 5 kHz across this band, but plot points are shown only for 25-kHz increments to avoid crowding of the data.) This evidence refutes the oft-heard statement that the SWR-vs.-frequency curve is *always* lowest at antenna resonance. Points to remember are that the SWR in a transmission line is completely dependent upon the characteristic-impedance value of the line in use. Using a line of different impedance may shift the position of the SWR curve along the frequency axis in a simple SWR-vs.-frequency plot. This is definitely true in this case — if the 160-meter half-wave dipole were to be fed with 75-ohm line, the lowest SWR would occur at a frequency about 5 kHz *below* antenna resonance, whereas with 50-ohm line the lowest SWR is at a frequency slightly *above* resonance. The reason this happens is that the resistive component of the impedance, which consists of the radiation resistance plus any loss resistance, is not constant with frequency, even over a rather narrow frequency range. It must be acknowledged that the differences here are very slight, however, and for practical purposes the frequency of lowest SWR is (within a few kilohertz) the resonant frequency of the antenna.

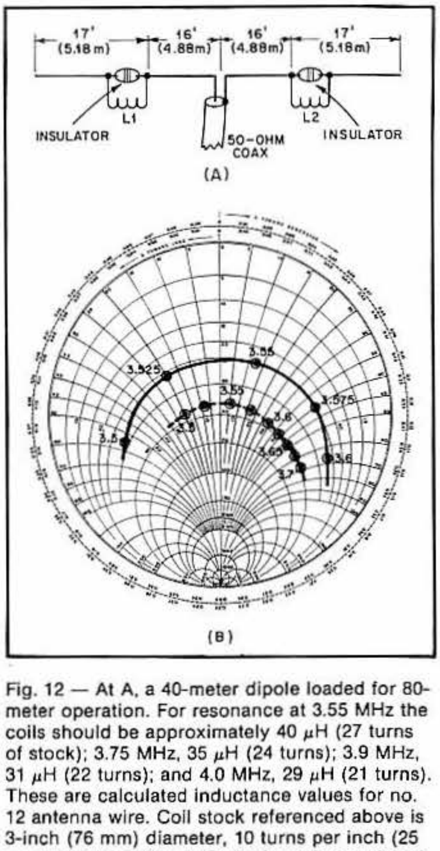


Fig. 12 — At A, a 40-meter dipole loaded for 80-meter operation. For resonance at 3.55 MHz the coils should be approximately 40 μH (27 turns of stock); 3.75 MHz, 35 μH (24 turns); 3.9 MHz, 31 μH (22 turns); and 4.0 MHz, 29 μH (21 turns). These are calculated inductance values for no. 12 antenna wire. Coil stock referenced above is 3-inch (76 mm) diameter, 10 turns per inch (25 mm) (B & W 3035). At B, the impedance plot of the 3.55-MHz version (solid curve) and of an 80-meter half-wave dipole (broken curve).

Another point concerning the SWR values bears noting. The values as determined from the plots in the manner described above are quite accurate, having been determined by measurements with laboratory equipment. In contrast, measurements with simple SWR indicators usually cannot be relied upon for anywhere near the equivalent accuracy.

For example, the author owns a commercially manufactured SWR indicator of the Monimatch type (see McCoy[4]) which, under a particular set of conditions, indicates a 2.5:1 SWR in a line where laboratory measuring equipment shows the *true SWR to be 4:1.* A significant difference! Herein lies another reason why impedance plots on Smith Chart coordinates are more meaningful than a simple SWR-vs.-frequency curve — greater accuracy may generally be expected.

A Half-Size 80-Meter Antenna

Fig. 12A shows the 3-band concept described earlier as it can be applied to 80, 40 and 20 meters. Its overall length is 66 feet (20.12 m), not a difficult length to use on a small lot. This antenna was constructed for 80-meter operation with a design-center frequency of 3.55 MHz, using no. 12 antenna wire and 40-μH loading coils — 27 turns of stock having a diameter of 3 inches (76 mm) and a pitch of 10 turns per inch (25 mm) (tpi). Feed-point impedances versus 80-meter frequency for the antenna, hung at a height of 50 feet (15.24 m), are shown by the solid curve at B of Fig. 12. Actual resonance occurred at 3.54 MHz, where the resistance was about 26 ohms. The bandwidth within which the SWR is 3:1 is 60 kHz, or 1.69 percent of the resonant frequency.

Also shown in Fig. 12B, by the broken curve, are the feed-point impedances of a half-wave dipole, 132 feet (40.23 m) overall length, hung in place of the shortened antenna. Resonance occurs at 3.54 MHz, where the resistance is 43.5 ohms and the SWR is 1.15:1. The broader nature of the half-wave antenna is exhibited by the "tighter" curve which swings closer to the 50-ohm center point of the chart than the shorter, loaded antenna. The SWR at 3.5 MHz is 1.6:1, and remains below 3:1 to 3.67 MHz.

Capacitive and Inductive Loading

One would assume that a combination of capacitive and inductive loading might provide a different feed-point impedance than would inductive loading alone, because of different current distributions in the radiators. To check out this assumption, the antenna of Fig. 12A was used as a "test bed" for comparative measurements. Capacitance hats were attached at different points along the 17-foot (5.18 m) lengths of wire outside the coils, and the coils were pruned to reresonate the antenna at about the same frequency as before. The impedance measuremnts were then repeated.

Dangling End Sections

First, "hats" consisting of 18 inches (457 mm) of no. 12 wire were affixed to the antenna ends and permitted to dangle. This lowered the resonant frequency to 3435 kHz. By calculations, this was approximately the same effect as that of extending the 17-foot portions of the antenna by the same amount as the dangling lengths, so it

Table 4

Characteristics of Various Loading Techniques, 66-Foot, 80-Meter Dipole

Loading	*Approx. feed-point resistance, resonance*	*SWR at resonance*	*3:1-SWR bandwidth, % of resonant freq.*
40-μH coils only	26 ohms	1.92:1	1.69
36.5-μH coils, 18" dangling ends	26	1.90:1	1.79
36" hats outside 32.5-μH coils	23	2.15:1	1.68
30-μH coils, 36" hats at ends	25	1.98:1	2.05
None (λ/2 dipole)	43.5	1.15	Greater than 3.6

Coil positions for each loaded antenna were 16 feet from antenna center. All antennas were constructed of no. 12 wire and installed at a height of 50 feet.

Feet X 0.3048 = m.

Inches X 25.4 = mm.

would seem to make little difference whether short sections of extra length are added inside the supporting insulators or are at the ends, suspended at right angles to the main antenna wire.

The inductors were reduced from 40 to 36.5 μH (25-turn coils replaced the original 27-turn coils), and resonance occurred at about 3575 kHz. At this frequency the resistance was 26 ohms and the SWR 1.90:1. The 3:1-SWR bandwidth, 64 kHz, is 1.79 percent of the frequency of resonance. The impedance plot for this arrangement is shown as Curve A in Fig. 13. The resistance at resonance for this antenna is identical to that with the coils alone, and the bandwidth is only 4 kHz greater, 64 kHz vs. 60. From these results, one would conclude that the main advantage offered by the "danglers" is a small saving of space over a flat-top antenna.

Capacitance Hats near Loading Coils

Next the dangling end sections were removed and a pair of capacitance hats was formed, each from two 36-inch (0.91 m) lengths of no. 12 solid wire. The two wires for a single hat were attached at their centers to the antenna wire at a point just outside one of the loading coils. The hat wires were then bent radially to form an X at right angles to the antenna wire, like four spokes of a wheel with the main antenna wire at the hub. The diameter of the X-shaped hat was thus 36 inches. The second hat was placed in a like manner just outside the second coil. Burndy connectors were used to affix the hat wires. The resonant frequency of this configuration with the original 40-μH loading coils was found to be 3290 kHz. The effect of adding the hats was about the same as that of extending the 17-foot (5.18 m) lengths to 19 feet (5.79 m).

When the inductors were replaced with 23-turn coils (32.5 μH), the antenna resonated at about 3.575 MHz, the resistance being 23 ohms. The SWR at resonance is 2.15:1, and the 3:1-SWR bandwidth for this configuration is 60 kHz, 1.68 percent of the resonant frequency. The impedance of this arrangement versus frequency is shown by Curve B of Fig. 13.

It is surprising to note that, by the standards of most amateurs, the characteristics of this antenna are not as good as those of the same length antenna with loading coils alone. The SWR at resonance for the antenna with combination capacitive and inductive loading is higher (2.15 vs. 1.92), and the 3:1-SWR bandwidths are the same, 60 kHz. Perhaps a significant factor here, though, is that the diameter of the capacitance hats used for these measurements was small, only 0.011 wavelength. Supporting much larger hats presents mechanical problems with wire antennas, however, as even these were a bit flimsy and would require reshaping after gusty weather.

Capacitance Hats at Antenna Ends

Finally, the X-shaped capacitance hats were moved to the outside ends of the antenna, just inside the end insulators. With the original 40-μH coils, resonance appeared at 3215 kHz. From calculations, it was as if the 17-foot (5.18 m) end sections were actually 21 feet (6.40 m) long. With 30-μH coils (22 turns) in place, the resonant frequency was 3560 kHz. At this frequency the resistance was 25 ohms and the SWR 1.98:1. The 3:1-SWR bandwidth is 73 kHz, or 2.05 percent of the resonant frequency. The impedance plot of this antenna is given in Fig. 14.

It is interesting to note that the position and shape of the plot for this antenna on Smith Chart coordinates is nearly identical to that for the same length antenna with loading coils only, the solid curve of Fig. 12B. For this antenna, however, the plot points for 25-kHz frequency increments appear closer together, which accounts for the increased bandwidth.

Conclusions

The measured characteristics of these various configurations of loading for the 80-meter antennas are tabulated in Table 4. Remember that the overall "flat-top" length of each antenna arrangement is 66 feet (20.12 m), and that the loading coils are always positioned 16 feet (4.88 m) each side of the center of the antenna, being pruned for resonance at approximately 3550 kHz. For comparison, information for a half-wave dipole is also included.

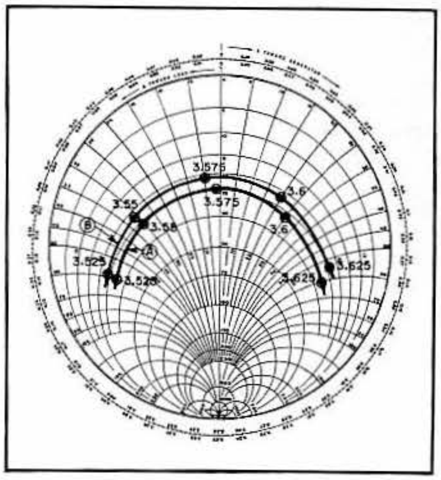


Fig. 13 — Curve A is the impedance plot of the antenna of Fig. 12A with 18-inch (457 mm) dangling end sections added and the coil trimmed to restore resonance near the original frequency. Curve B is a plot of the same antenna with X-shaped capacitance hats added at a point just outside the loading coils (dangling sections removed and coils trimmed to reestablish resonance.).

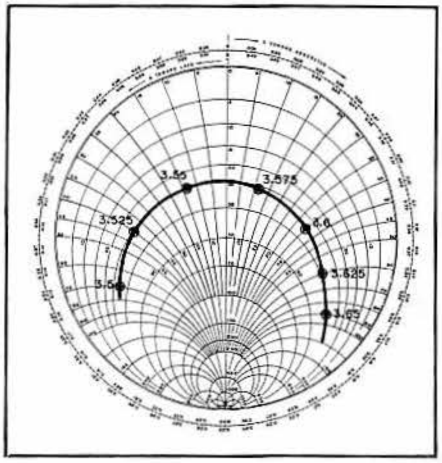


Fig. 14 — Impedance plot of a 66-foot (20.12 m) dipole using a combination of off-center inductive loading and capacitive end loading. Of all the shortened configurations tried, this arrangement offered the greatest bandwidth.

Of the various arrangements, capacitive end loading decidedly provides the greatest bandwidth, excepting the full-size half-wave antenna, of course. Although there are slight differences in the resistance value at resonance, all are of the same order of magnitude. These values, as well as those for the 160-meter antenna discussed earlier, tend to confirm a *broad* rule of thumb that the writer has formulated for this type of antenna: The feed-point impedance value at resonance is roughly proportional to the length of the antenna. That is, a loaded antenna which is half the size of a half-wave dipole will have approximately half the radiation resistance of the full-sized antenna.

Eq. 1 given earlier or the chart of Fig. 9 allows one to calculate loading-coil values for antennas with loading coils only. Additional capacitive loading is not taken into account. Calculating the effects of various capacitive loading arrangements appears to be difficult, and work remains to be done in this area.

Multiband Antennas with Loading Coils

All of the foregoing material has been devoted to the loading of an antenna for resonance at a single frequency. Resonated as described, the antenna is electrically a half wave in length. It will, however, operate well on higher frequencies — frequencies at which it is an odd multiple of half waves in *electrical* length . . . three half waves, five half waves, etc. Because of the lumped loading of the shortened antenna, these higher frequencies will likely not be closely related to odd-order harmonics of the fundamental frequency, as the case would be for a nonloaded radiator. (For example, it is a well-known fact that a 7-MHz half-wave dipole operates well on its third harmonic, 21 MHz.)

A loaded dipole will become an electrical 3/2-λ antenna at some frequency below that which is three times the fundamental resonant frequency. Depending upon the overall antenna length, coil value, and coil position, it is possible for an 80-meter loaded dipole to become a 3/2-λ performer on 40 meters. With such an arrangement, one would have a dual-band antenna without requiring the use of traps. The idea can be expanded upon to arrive at a loaded antenna without traps which will operate on more than two bands. This scheme offers considerable constructional simplification as compared with trap arrangements.

The multiband loading-coil concept has been recognized for better than half a century, but little use of the technique has been made by amateurs. Some years ago a very good article on the subject was published by William Lattin, W4JRW.[5] That article is recommended reading for anyone interested in more details on the concept. Supplemental information has been published by Buchanan.[6] Attempts by this writer to calculate antenna sizes and coil values for dual-band antennas have met with some success. From calculations and experiments to date, it appears that with only two loading coils (one each side of center), the antenna must always be greater than a half wave in physical length for the higher of the two frequency bands. In other words any 80/40 meter arrangement, for example, apparently would need to be longer than 66 feet (20.12 m) from tip to tip. However, much work also remains to be done in this area. This material was originally presented in *QST* by Jerry Hall, K1TD.

References

[1] Sevick, "The Ground-Image Vertical Antenna," *QST*, July 1971. (See chapter 1.) Also, "The W2FMI Ground-Mounted Short Vertical," *QST*, March 1973. (See chapter 1.) "A High Performance 20-, 40- and 80-Meter Vertical System," *QST*, December 1973. (See chapter 1.) "The Constant-Impedance Trap Vertical," *QST*, March 1974, p. 29.

[2] LaPlaca, "Using the ARRL L/C/F Calculator," *QST*, December 1973, p. 26.

[3] Hall and Kaufmann, "The Macromatcher, An Rf Impedance Bridge for Coax Lines," *QST*, January 1972, p. 14. Information also contained in *The Radio Amateur's Handbook* and *The ARRL Antenna Book*.

[4] McCoy, "Monimatch, Mark II," *QST*, February 1957, p. 38. Also, "An Etched-Circuit Monimatch For Checking Your Antenna System," *QST*, October 1969. (See chapter 4.)

[5] Lattin, "Multiband Antennas Using Loading Coils," *QST*, April 1961, p. 43.

[6] Buchanan, "An Inexpensive 40- and 80-Meter Antenna, Hints and Kinks," *QST*, September 1962, p. 62.

Efficient Short Radiators

If you're cramped for space to put up a beam antenna, you'll want to investigate these ideas as one way to shrink 'er down to usable size.

Shortened antennas have been popular with amateurs for either esthetic, space limitation or economic reasons. And most are inefficient radiators with narrow bandwidth. This section will first define some limitations and problems of conventinal short antenna designs. A design for a half-size 2-element Yagi, the performance of which is competitive with its full-size equivalent, will follow.

It has been proved that no appreciable difference exists between the directive patterns of "short" and full half-wave horizontal dipoles. Since the gain of a half-wave dipole over an isotropic radiator is determined by the dipole directive pattern and since the length of the dipole (up to $\lambda/2$) has negligible effect on its directive pattern, the length of the dipole (up to $\lambda/2$) has a negligible effect on its gain. An assumption is made that the efficiencies of both the short and half-wave dipoles are equal. The efficiency of an antenna can be expressed as

$$\text{Eff} = \frac{R_r}{R_r + R_{loss}} \qquad \text{Eq. 1}$$

where R_r = radiation resistance

R_{loss} = loss resistance of conductors, coils, etc.

The radiation resistance (R_r) of a horizontal dipole is determined by its length and height above ground. In free space, the R_r of a half-wave dipole is 73 ohms. As the length of the dipole is reduced, the R_r decreases as the square of the length. Thus, for a half-size dipole (as compared with $\lambda/2$), the R_r decreases to a value one-fourth that of the $\lambda/2$ dipole or approximately 13 ohms.

The efficiency of a half-wave dipole is very high, being on the order of 95 percent. The R_r is large and R_{loss} small by comparison. If we reduce the overall length by a factor of two, the R_r decreases by a factor of four. Input impedance at the center of the dipole is comprised of a low resistance and large capacitive reactance, so inductive loading is required in order to resonate the dipole. The inductive reactance needed to center-load the antenna will be approximately 1 kΩ (depending on conductor size used for the antenna). Assuming a coil Q of 200 and computing efficiency using Eq 1: This means that 28 percent of the transmitting power applied to the antenna is dissipated in the loading coil. The author has neglected any additional losses in the matching network which would result if the above antenna were driven by a 50-ohm source.

Let's suppose we decide to build a 2-element Yagi using shortened center-loaded elements. The driven element by itself has an R_r of 13 ohms. Adding a close-

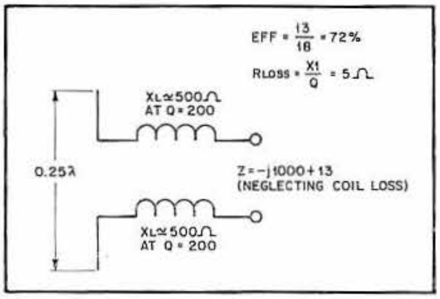
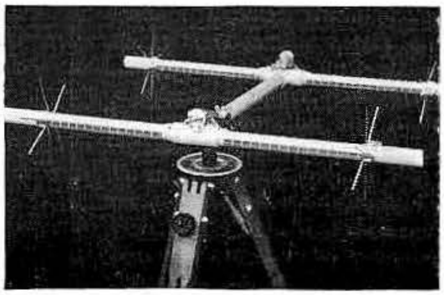


Fig. 15 — Electrical equivalent for the center-loaded dipole discussed in the text. Efficiency is 72 percent, as determined by Eq. 1.



The 100-MHz "model" used by the author for testing shortened elements in a Yagi antenna design.

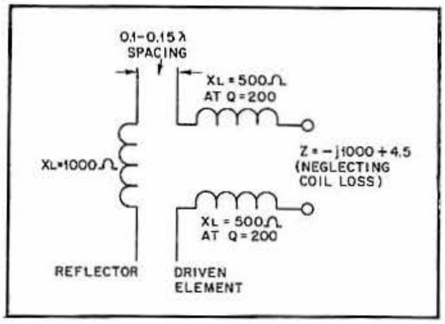


Fig. 16 — Electrical equivalent of a loaded 2-element antenna. The efficiency is 47 percent.

spaced parasitic element reduces the radiation resistance by approximately a factor of three. Thus, the driven element has an impedance composed of approximately 4.5 ohms resistive and 1 kΩ reactive. Loading both the driven and parasitic elements with the same inductors that were used for the dipole and computing efficiency

$$\text{Eff} = \frac{4.5}{4.5 + 5} = 47 \text{ percent}$$

This efficiency equates to slightly more than a 3-dB power loss in the driven element. The writer has neglected the sizable loss in the matching network since it must transform the 50-ohm source to the 9.5-ohm impedance of the antenna at resonance. In addition, the loading coil of the parasitic element will contribute approximately 1 dB of loss.

Taking into account the losses on loading coils of both the driven and parasitic elements and the loss on the driven element to feed-line matching network, we can easily account for a 5-dB power loss. Such a power loss would nullify the gain of a properly tuned Yagi, making it little better than a full-size dipole.

It should be obvious from the previous examples that the poor performance of short dipoles, and particularly Yagis, is a direct result of losses in loading inductors. If we can reduce these losses while raising the radiation resistance, the increase in efficiency will (might?) make the short dipole or Yagi competitive with its full-size counterpart.

Test Antenna

The helically wound whip antenna has always been appealing because the R_r tends to be higher than that of the base-loaded whip. This is because it is continuously loaded. In fact, using end-loading (large capacitance hats), the current distribution will be much more constant, yielding an R_r of up to four times that of a base-loaded whip. The author decided to use the helical design for a short test dipole and investigate the properties of this antenna versus that of a full-size dipole.

Conventional design for a helically wound antenna uses a form (wood, bamboo, fiberglass) wound with approximately λ/2 of no. 14 wire per λ/4 element. The writer felt that the resistive R_{loss} of this large amount of wire would be as great as that of the loading coils in the center-loaded dipole, making the helical design ineffective. As it is desirable to reduce conductor resistance, the surface area of the conductor must be substantially increased. Tubing is not mechanically suitable, and because skin depth is only on the order of 0.001 inch (0.03 mm),[1] the use of tubing is not required. Some 1/2-inch (13 mm) wide copper tape[2] was on hand and a study of its skin resistance revealed a loss per unit length of 12 percent less than that of the no. 14 wire.

A helically wound dipole was constructed (using the 1/2-inch [13 mm] wide tape) for use at 100 MHz. This frequency was chosen so that field-strength measurements could be performed using a local fm broadcast station as the signal source. A 28-inch (711 mm) length of 3/4-inch (19 mm) CPVC tubing (plastic water pipe) was wound with 38 equally spaced turns of the 1/2-inch (13 mm) wide tape. Using a grid-dip meter, resonance was measured at 104 MHz. Next, two 5-1/2-inch (140 mm) diameter six-spoke capacitance hats were attached to the ends. Resonance was again measured and found to be 84 MHz. A C-match[3] was constructed to transform the low impedance of the short dipole to 50 ohms. The C-match requires that the element be made to look inductive by lowering its resonant frequency. A variable capacitor is then shunted across the feed point and adjusted for resonance. This L/C ratio determines the impedance transformation. A 100-pF variable capacitor was shunted across the feed point of the test dipole and a 50-ohm coaxial cable was attached. Since the dipole is a balanced antenna, feed-line decoupling was necessary. The author used a quarter-wave sleeve (bazooka).

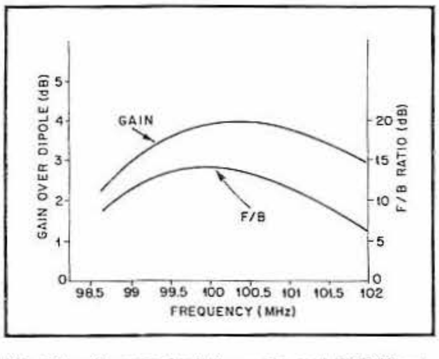


Fig. 17 — Curves depicting gain and FBR (front-to-back ratio) vs. frequency when the Yagi antenna is tuned for operation at 100 MHz.

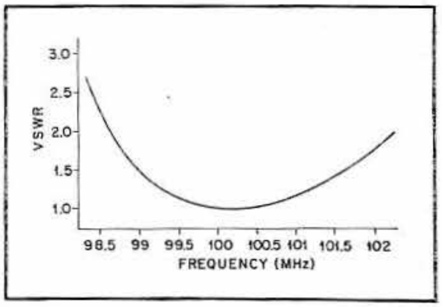


Fig. 18 — VSWR vs. frequency when the Yagi antenna is tuned for operation at 100 MHz.

Antenna Tuning

Rf power was applied to the test antenna through an SWR meter (measurements were taken in a screen room). Turns were removed, one at a time, and the shunt capacitor adjusted until a 1:1 match occurred. The capacitance hats were always installed at the tips of the element. When adjusted for a 1:1 match, the dipole consisted of 32 turns of copper tape, center fed, with 40 pF shunting the feed point and an overall element length of 21 inches (533 mm) which is 37 percent of the length of a full-size dipole. Tuning was very simple and took but 15 minutes to complete.

Measurements

The feed-point impedance was measured (with C-match disconnected) to be 20 ohms. The skin depth resistance was computed to be 0.24 ohm. Computing efficiency

$$\text{Eff} = \frac{20}{20 + 0.24} = 98 \text{ percent}$$

which is essentially the same as a full-size dipole. Bandwidth between 2:1 SWR points was measured to be greater than 6 percent of the operating frequency. Large capacity hats (for 100 MHz) and wide tape play an equally important role in reducing the Q of the antenna sufficiently to obtain a wide bandwidth. Next, a low-level signal generator and dipole were set up 5 wavelengths away from the test antenna. Using an Empire NF-105 noise and field-strength meter, a comparison was made on field strength between the test antenna and a full-size dipole. Results indicated no apparent measurable difference between the short helically wound dipole and a full-size dipole. Field-strength measurements were then taken on the signal from a local fm broadcast station. Again, there was no apparent difference; not bad for an antenna that is less than half size. The next question to be answered was whether gain could be secured by the addition of a parasitic element.

A boom and a parasitic element were added to the shortened test dipole. Although a director might provide better gain and front-to-back ratio (FBR), the decrease in radiation resistance, to a very low value (dipole by itself equals 20 ohms) because of the close spacing, was thought to decrease efficiency and bandwidth. A parasitic reflector was constructed, similar to that of the driven element. The element was split in the center and a 100-pF capacitor installed for tuning purposes. Element spacing was adjusted to 0.15 λ. With the capacitor fully meshed, the six-spoke capacitance hats were physically positioned on the element (both equidistant from element center) so that the reflector resonated at 93 MHz. Nominal reflector tuning calls for reflector resonance approximately 5-percent lower in frequency than the driven element, or 95 MHz. With the above configuration, the author was able to adjust reflector resonance, using the variable capacitor, anywhere in the range of 93 to 96.5 MHz or 3.5 to 7 percent lower in frequency than the driven element.

Using the same field-strength measurement set up as with the dipole, the reflector was aimed at the source signal and adjusted (using the variable capacitor at element center) for minimum pickup. The driven element was then readjusted for a 1:1 SWR and the process repeated until minimum rear pickup and a 1:1 SWR occurred simultaneously. Gain and FBR measurements were made at the design frequency and at points two percent of the design frequency on either side. The results are described in Fig. 17. The bandwidth measurements are given in Fig. 18.

As can be seen from the curves in Fig. 17, a gain of 4 dBd, and a 15-dB FBR can be secured quite easily with a physically short Yagi. As with other Yagis, the gain is relatively constant over a wide frequency range. However, the FBR drops quite fast especially when trying to use the antenna below its design frequency. From curves given in Fig. 18, the bandwidth between the 2:1 VSWR points is shown to be about 3.7 percent. Translated to 20 meters this bandwidth would be 500 kHz, equal to or greater than the average 3-band trap Yagi. If indeed the design were scaled to 14 MHz, the antenna would have element lengths of slightly over 12 feet (3.66 m) and a boom length of 10 feet, 6 inches (3.20 m).

Adapting Design to Ham Bands

Since it has been shown that a physically short Yagi can provide significant gain and FBR, a few design pointers are in order. First, make the element length no shorter than physically necessary for your particular situation. Bandwidth and efficiency will improve with greater lengths. Second, the use of large capacitance hats is recommended, as this reduces the helical conductor length and thus R_{loss}. Third, use large forms of good dielectric quality (fiberglass). The larger the form diameter, the greater the length reduction for a given number of turns. Also, with large diameter forms, 1.5 inch (38 mm), the width of the conductor can be increased, thus reducing R_{loss}. Fourth, regardless of the matching network used, construction of capacitance hats, etc., *solder all* joints and *seal* with silicone rubber. *Do not rely on pressure joints.* Fifth, to secure a reasonable FBR with any Yagi using a split driven element and fed with coaxial cable, some form of balun transformer is required to keep currents from flowing on the outside of the coax braid. Sixth, the use of a grid-dip meter is the only practical method to secure resonance with a fixed physical length. Construction will require some cut and try. Proximity to surrounding objects will affect resonance, and should be avoided when tuning the array.

No doubt the author has left out items, which may prove to be a problem for the reader. This article was intended to be more thought provoking than constructional, although there should be enough information here to build your own antenna with a reasonable amount of experimental effort. My current plans call for construction of a 2-element 10-meter Yagi (for reception of OSCAR signals) with 6-foot (1.83 m) elements and a 5-foot (1.52 m) boom. The author wishes to thank Mike Povlich, WB9HGS and Russ Mills for their assistance with measurements. This material was originally presented in *QST* by Ronald J. Gorski, N9AU.

References

[1] Kuecken, *Antennas and Transmission Lines*, Howard W. Sams and Company, Indianapolis, IN, 1st Edition (1969), p. 274.

[2] Copper tape available from Minnesota Mining and Mfg. Check Yellow Pages for the address of a local distributor.

[3] Orr, *Beam Antenna Handbook*, Radio Publications Inc., Wilton, CT, 3rd Edition, p. 63.

Simple Arrays of Vertical Antenna Elements

Work DX with a vengeance! Simple arrays of vertical elements will provide good low-angle radiation. DXCC may be closer than you think if you can manage a system like this one!

Because of the excellent low-angle radiation properties of vertical antenna elements and because of the benefits to be gained by horizontal-plane directivity, it is interesting to attempt to determine "optimum" arrangments of elements to produce "beam" antenna arrays. Because of the enormous variety of configurations possible, and the great difficulty of either experimental modeling or calculating exact theoretical performance, it has not been practical in the past to arrive at valid conclusions. However, it is now quite easy to simulate such antenna arrays by computer programs, and these can produce relatively quick and precise answers to a very large number of postulated configurations. After a number of computer trial runs, "optimum" configurations can be found quite readily. Such a computer program for quarter-wave elements has been written and supplied by H. Hurwitz, WA2VBW. Using a modification of this program, the author has investigated a

Table 5

Case	Element	Current	Phase	X	Y	Beam Direction	Beam Gain	Back Radiation	Minor Lobes
1	1	1	0	0	0	0°	3 dB	-3 dB	-α
	2	1	-90	0.25	0				
2	1	1	0	0	0	0°	4.1 dB	5.7 dB	-11.5
	2	1	-120	0.25	0				
3	1	1	0	0	0	90°	1.1 dB	0 dB	0 dB
	2	1	0	0.25	0				

Table 6

I1	I2	$\phi 1$	$\phi 2$	Beam Gain	Back Radiation	Minor Lobes
1	0.8	0	-120	4.0 dB	-5.5 dB	-10.8 dB
1	1	0	-120	4.1	-5.7	-11.5
1	1.2	0	-120	4.1	-5.6	-12.5
1	1	0	-100	3.4	-3.8	-11.1
1	1	0	-120	4.1	-5.7	-11.5
1	1	0	-140	4.6	-6.6	-6.6

Table 7

Element	Current	Phase	X	Y	Beam Direction	Beam Gain	Back Radiation	Minor Lobes
1	1	0	0	0	0°	5.6 dB	-8.7 dB	-8.7 dB
2	1	-120	0.25	0				
3	1	-240	0.5	0				

Table 8

Element	Current	Phase	X	Y	Beam Direction	Beam Gain	Back Radiation	Minor Lobes
1	1	0	0	0	90°	2.7 dB	0 dB	0 dB
2	1	0	0.25	0				
3	1	0	0.5	0				

Table 9

Element	Current	Phase	X	Y	Beam Direction	Beam Gain	Back Radiation	Minor Lobes
1	0.5	0	0	0.145	0°	4.35 dB	-6.1 dB	-15. dB
2	1	-110	0.25	0				
3	0.5	0	0	0.145				

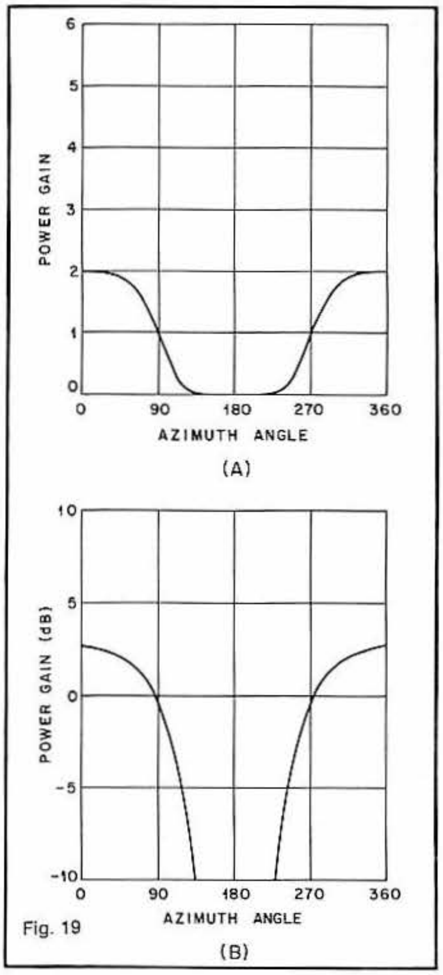


Fig. 19

large number of simple array configurations, which are potentially quite useful at the lower amateur frequencies, with the salient results given here. It is hoped that these will prove interesting to those considering construction of such arrays.

Technique for Optimizing Arrays

We must first try to define the problem and the parameters leading to an optimum design. The horizontal-plane pattern of an array of (vertical) elements depends only on the magnitudes of the individual element currents and their phases, and not on the way the currents are produced (e.g., driven or parasitic). The computer program allows one to specify the locations (x,y coordinates) of any number, n, of quarter-wave elements; also one must specify the magnitude of current and its phase in each element (usually normalized to unity current and zero phase for a given fiducial element). With these data inputs the radiation pattern is calculated and plotted out, giving the relative power gain in each azimuth angle interval, say, 5 or 10 degrees. The power gain is normalized to that power which would have been radiated at the same azimuth by a *single* vertical element using the same input electrical drive power. By using trial values of the current in all elements, in both amplitude and phase, one soon develops a feel for the behavior of the system, and can usually arrive at a "best" value for all the currents and phases. One can then try different geometrical separations of the elements and in this way arrive at the "best" spacing. Usually this best configuration is a compromise between power gain and good pattern control, e.g., front-to-back ratio, or more generally, main lobe to minor lobe (side or back) ratio.

In addition to the optimization described above it must be noted that if the array is to be used primarily to produce a "beam" in a given general direction with little emphasis on other directions, one usually finds a linear array of elements best (equivalent to an end-fire Yagi array). However, if the array is to be used for all directions, a more (circularly) symmetrical array should be considered. These points will become clear in the discussion of results.

Two-Element Array

In the case of two elements there is only one possible configuration. Consider one element at the origin of the x,y plane (coordinates 0,0) and the other element along the x axis (coordinate x,0). The parameters available are x, which we specify in units of wavelength, λ, the rf currents I1 and I2 in each element (we shall normalize one of the currents, e.g., I1, to unity) and the phases, $\phi 1$ and $\phi 2$, of the currents (we shall generally normalize the phase of the current in element 1 as zero and specify the relative phase of the current in element 2 in electrical degrees, either positive for leading currents or negative for lagging currents). It soon becomes apparent that the region of main interest is where the spacing x is in the neighborhood of 0.25, i.e. $\lambda/4$, and there the currents are nearly equal in magnitude. The reasons are that, for spacings of 0.5 or greater, other strong lobes appear in the pattern, and for grossly unequal currents relatively poor

Table 10

Element Spacing	*Optimum $\phi 2$*	*Beam Gain*	*Back Radiation*	*Minor Lobes*
0.2	-130°	4.65 dB	-6.5 dB	-18 dB
0.25	-120°	4.6	-6.5	-16
0.3	-110°	4.4	-6.2	-14
0.35	-110°	4.2	-5.8	-12

Table 11

Element	*Current*	*Phase*	*X*	*Y*	*Beam Direction*	*Beam Gain*	*Back Radiation*	*Minor Lobes*
1	1	0	0	0	0°	7.4 dB	-9.9 dB	-9.9 dB
2	1	-120	0.25	0				
3	1	-240	0.5	0				
4	1	0	0.75	0				

Table 12

Element	*Current*	*Phase*	*X*	*Y*	*Beam Direction*	*Beam Gain*	*Back Radiation*	*Minor Lobes*
1	1	0	0	0	90°	4.2 dB	0 dB	0 dB
2	1	0	0.25	0				
3	1	0	0.5	0				
4	1	0	0.75	0				

Table 13

Element	*Current*	*Phase*	*X*	*Y*	*Beam Direction*	*Beam Gain*	*Back Radiation*	*Minor Lobes*
1	1	0	0	0	45°	6.4 dB	-18 dB	-18 dB
2	1	-110	0.25	0				
3	1	-220	0.25	0.25				
4	1	-110	0	0.25				

Table 14

Element	*Current*	*Phase*	*X*	*Y*	*Beam Direction*	*Beam Gain*	*Back Radiation*	*Minor Lobes*
1	1	0	0	0	0°	5.1 dB	-11.5 dB	-11.5 dB
2	1	-120	0.25	0				
3	1	-120	0.25	0.25				
4	1	0	0	0.25				

Table 15

Square side Length (in λ)	*ϕA opt.*	*ϕB opt.*	*Beam Gain*	*Back Radiation*	*Minor Lobes*
0.167	-130	-260	6.6 dB	-22 dB	-22 dB
0.25	-110	-220	6.4	-18	-18
0.333	-80	-160	5.6	-18	-18

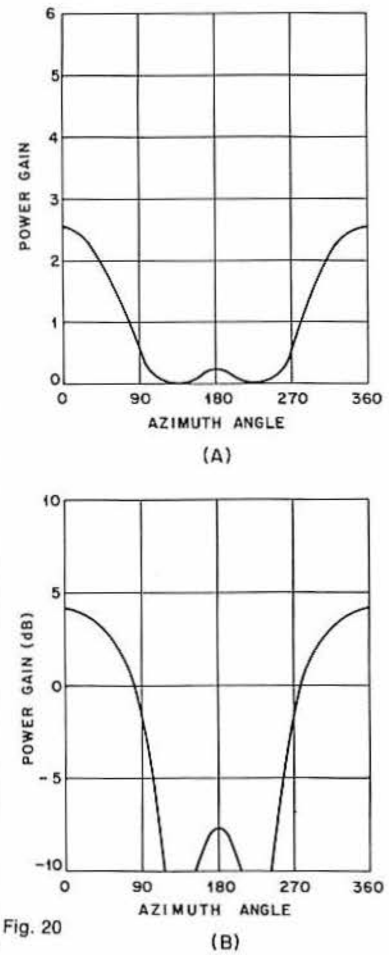


Fig. 20

peak gain and pattern discrimination result. Although the spacing x is not especially critical in the neighborhood of 0.25 (one can essentially compensate by adjustment of phase angle) we shall now examine the case where x = 0.25, and where I1 = I2 = 1. Best overall pattern discrimination (minimum back lobe) for the endfire case occurs where $\phi 1 = 0$, and $\phi 2 = 90$ degrees, and the power-gain pattern is shown in Fig. 19A.

Peak gain is 2 (or 3 dB) and occurs along the x-axis direction. Fig. 19A shows the power pattern of the array, i.e., it shows quantitatively where the radiated power goes. However, if one is looking at what an S meter would indicate, one can present exactly the same information on a vertical *logarithmic* scale as shown in Fig. 19B.

The vertical scale is shown in dB relative to the value for a single vertical radiator. This type of display is useful in judging excellence of pattern with respect to minor lobes. For all future cases discussed here, both displays will be shown.

It is possible to increase the gain of this array at the expense of some back lobe by increasing the phase lag in element 2, e.g., if $\phi 2 = -120$ degrees the peak gain, again along the x axis, is 2.59 (or 4.1 dB) and the entire pattern is shown again in Figs. 20A and B.

Note that the back lobe now shows a gain of 0.186, which is −11.5 dB relative to the forward lobe.

These two elements can be used to form either a beam along the +x axis as shown, or reversed along the −x axis (by reversing the phase $\phi 2$, i.e., making it +120 instead of −120 degrees) or if the two elements are driven in the same phase, i.e., $\phi 1 = \phi 2 = 0$, one produces a bilateral broadside beam as shown in Fig. 21.

Here the peak gain is 1.1 dB, but there is a "back" lobe of equal magnitude to the front lobe. Note that all patterns will be symmetrical around the x axis, or more generally around the line of any set of linearly-positioned elements. This example has illustrated some of the aspects of all of the results to be presented; namely, that:

a) The best element spacing will be found to be in the neighborhood of 0.25 wavelength.
b) Current ratios and phases can be adjusted to produce either a best *pattern discrimination* (minor lobe rejection) or best *main lobe gain.* It is generally not possible to get both at the same time, and a compromise must be made.

It may be useful to tabulate the salient results of each "best" case by noting the coordinates of the elements in the x,y plane, the individual drive currents, the individual phases, main beam heading in the x,y plane, main beam gain, and the

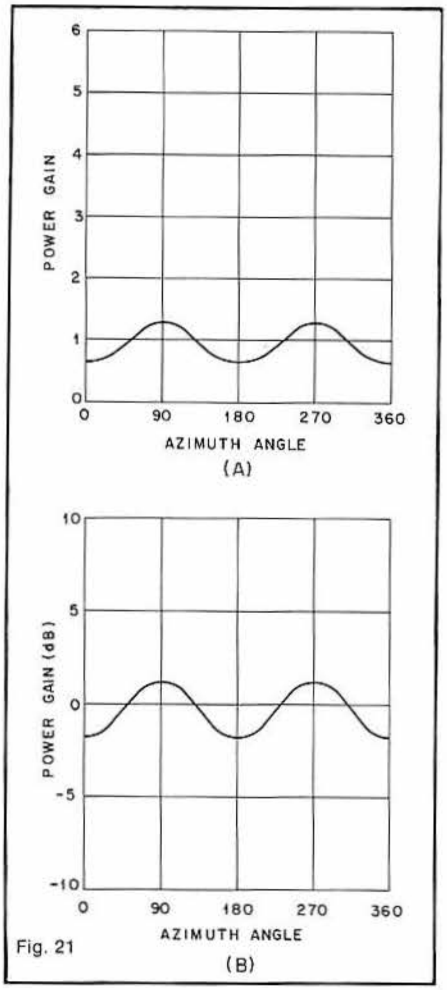


Fig. 21

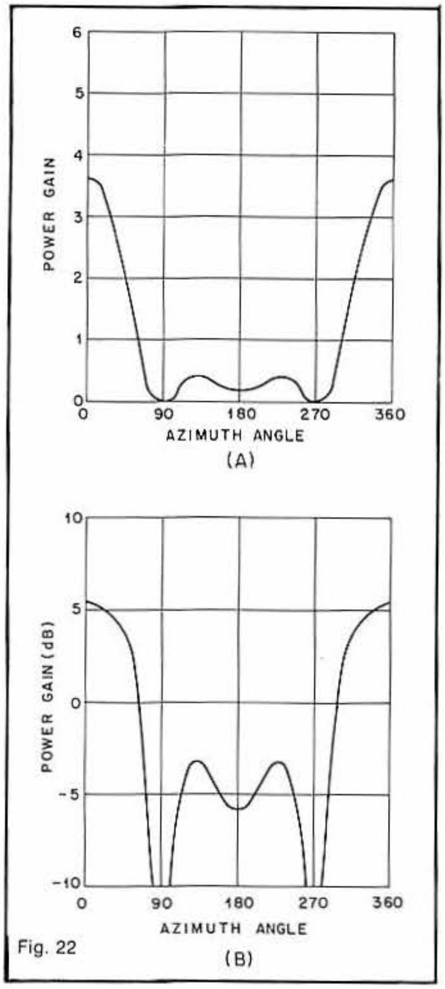


Fig. 22

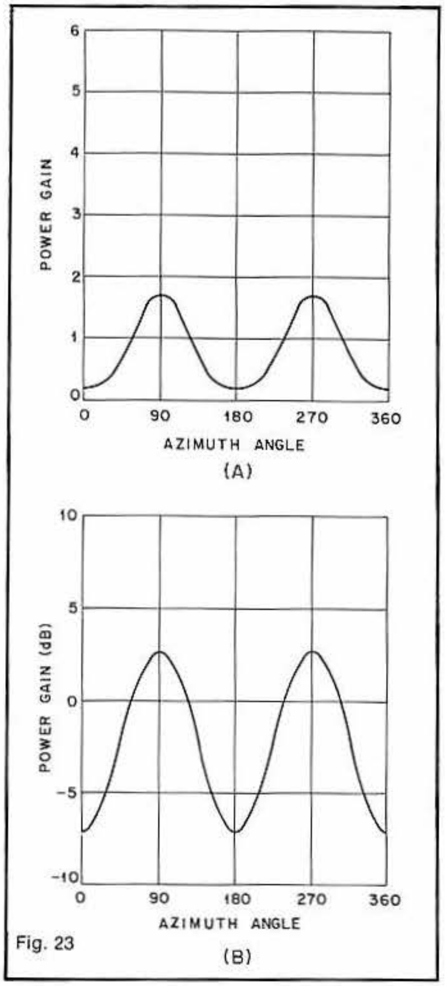


Fig. 23

largest pattern gain (such as given by either the side of the main lobe or by minor lobes) observed anywhere in the entire 180-degree sector centered just opposite in direction to the main lobe. We shall designate this quantity as "back radiation" and express it in dB relative to the main lobe gain. We shall also tabulate the largest minor lobe in this sector and label it "minor lobe," again expressed in dB relative to the main lobe. Thus for the cases just described, Table 5 is presented.

The sensitivity of these results to variations of currents and phases is not high. For example, one can summarize case 2 above with somewhat altered I2, or $\phi 2$, as shown in Table 6.

The author feels that end-fire case 2, where $\phi 2 = -120$ degrees, probably represents the "best" design with a good pattern and gain. Other more complicated cases presented below are optimized in this same way and only the "best" configuration will be shown with actual results.

Three-Element Arrays

For three elements, two different geometries suggest themselves: the linear array, best for a single preferred directional line, and an equilateral triangle configuration, the closest approach to circular symmetry. The latter, as we shall see, could be switched to give "beams" in any one of six angular positions (every 60 degrees). Let us consider first the linear array.

Linear Array — As in the 2-element linear array just discussed, the optimum arrangement seems to center around an element spacing of about 0.25 wavelength with approximately equal current drives. The optimum end-fire case is shown in Table 7; the broadside case is shown in Table 8.

The patterns for these cases are shown in Figs. 22 and 23.

Remember that for the end-fire case, which one can think of as a 3-element Yagi on its side, the rather large side lobe results because the pattern lies in a plane perpendicular to the elements. Side radiation is hard to avoid, as one cannot take advantage of the nulls off of the ends of excited elements.

Equilateral Triangular Array — For this case, the optimum situation appears to be as shown in Table 9. The behavior is very similar to the case of two elements in end-fire. See Table 5 (we have just split one of the two elements and have moved the separate pieces to the triangle corners). The pattern is shown in Fig. 24.

Reversing the phases will reverse the beam direction, and by rotating the drive currents (and phases) around the triangle, one can produce six beam directions (every 60 degrees). This is an attractive feature, but it does not come free; the maximum gain of the system is somewhat less than one obtains with the three linearly-disposed elements (which are chiefly useful in a direction along the line of the array).

The exact size of the triangular array is not critical — one must simply choose the best phase angle for the particular geometry. The "best" phase angles, $\phi 2(\phi 1 = \phi 3 = 0)$, as determined by computer runs, for different spacings (triangle side lengths expressed in terms of λ) are shown in Table 10.

Four-Element Arrays

With four elements, there are at least three configurations which are interesting to investigate. As before, the linear array with a preferred beam direction is one type, but there are two configurations which possess a measure of circular symmetry. One of these is described by three antenna elements at the corners of an equilateral triangle with the fourth element at the geometric center of the triangle. This one we shall designate as a center-filled triangle. The other type is a square array.

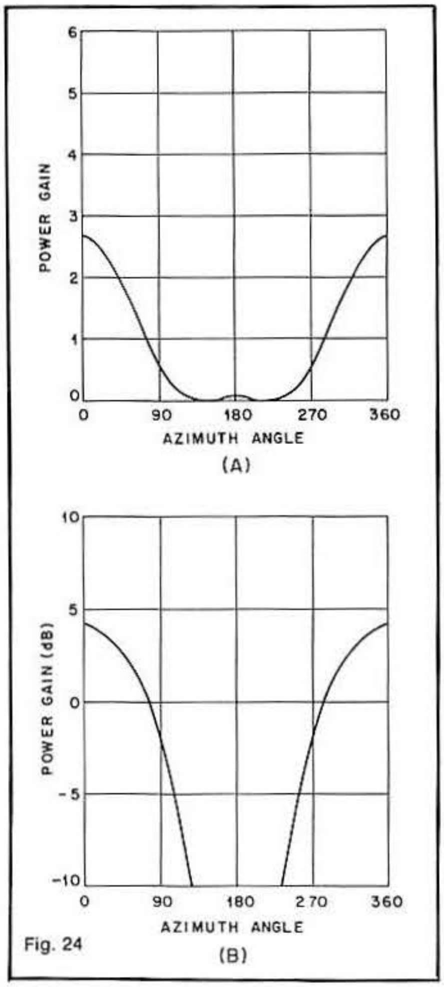


Fig. 24

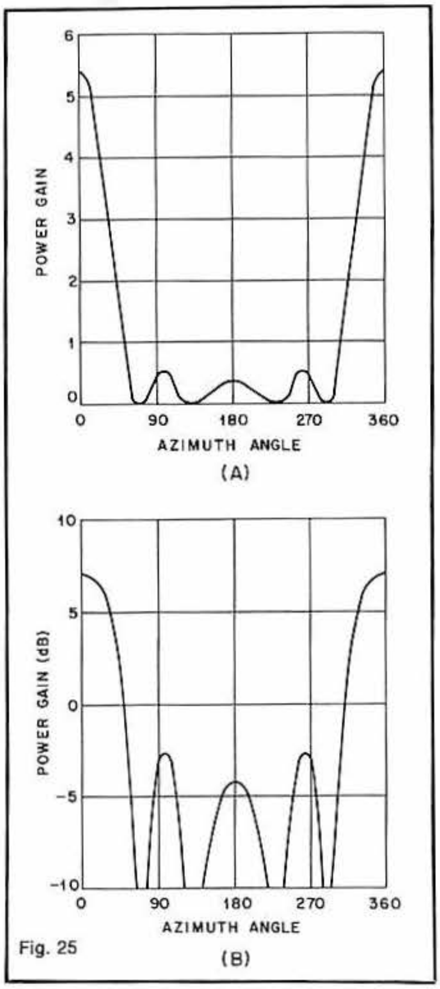


Fig. 25

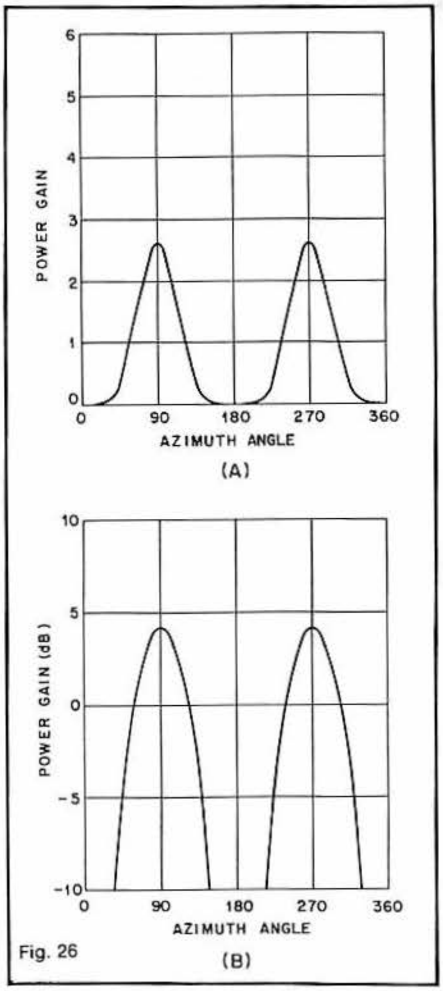


Fig. 26

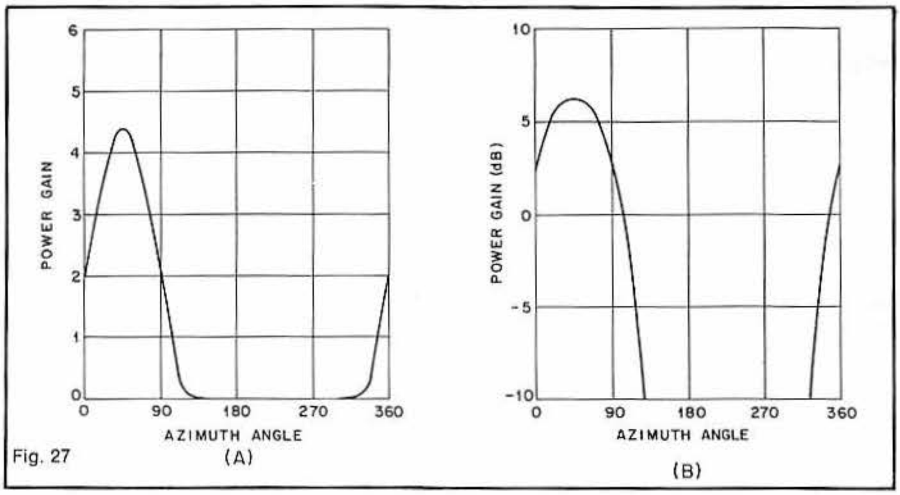


Fig. 27

Let us take these three types in order.

Four-Element Linear Array — For this case the optimum end-fire solution appears to be as shown in Table 11. The gain and major lobe shape of this configuration seems to be excellent. The broadside case is shown in Table 12. Patterns for this case are shown in Figs. 25A, B, and 26A, B.

Note that for this array there is poor coverage in some azimuthal directions (e.g., ±45 degrees) if only the two tabulated phase arrangements are used.

Center-Filled Triangle — A large number of situations were examined for this configuration, but unfortunately no combinations of spacing, currents or phases were found that looked very good. The best pattern was not particularly better than that of the three-element triangle alone, and was substantially inferior to that of the 4-element square to be discussed next.

Four-Element Square Array — For this case the best situation appears to be as shown in Table 13. Note that this arrangement fires diagonally and produces a respectable gain and excellent pattern. The "broadside" arrangement for the same square is shown in Table 14. The computed patterns are shown in Figs. 27 and 28.

The diagonal-fire pattern is exceptional, providing extremely low back radiation and minor lobes. The broadside pattern is not nearly as good, somewhat superior but reminiscent of the end-fire pattern obtainable with just 2 elements (see Fig. 20). In fact, the power-gain coverage at all angles (including the broadside angle) just using the switched four diagonal beams is large enough that it probably is not worthwhile using the broadside arrangement at all even to "fill" between diagonal beams.

This square array is superior to the center-filled triangle, and to all other simpler configurations (circular) in both gain and pattern discrimination. It is sufficiently good that one might ask what particular properties of the square have led to the nearly ideal performance. The

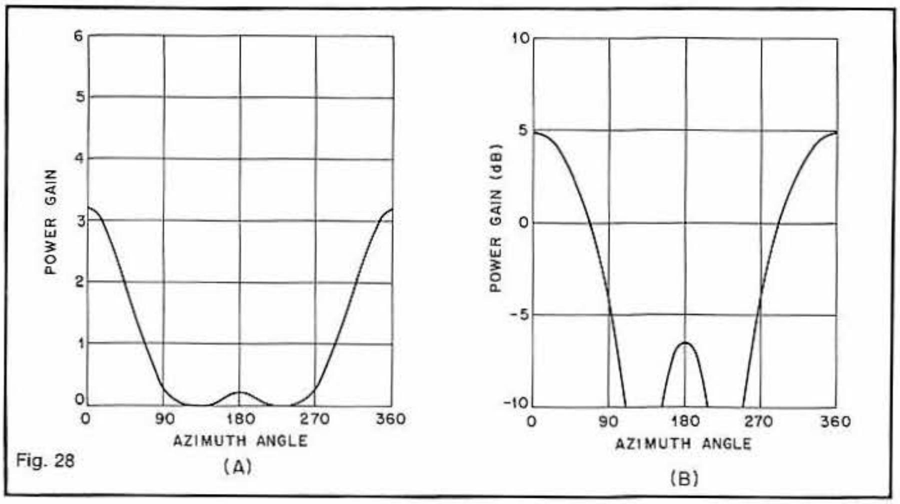


Fig. 28

(A)

(B)

author believes that there are two parameters which are noteworthy: first, the gain is respectable in diagonal fire because one can view the square along its diagonal as a three-element linear array in which the center element is split, each half being displaced to the other corners of the square. Thus the array behaves something like a 3-element (Yagi-like) linear array which is known to have a good gain. Secondly, the lobes are much smaller than the linear array due to the tendency for the phase cancellation of waves produced by the spatially-separated corner elements.

Again, as in previous examples, the actual dimensions of the square are not very critical, as long as one adjusts the phase (delay), ϕA in elements 2 and 4 and the larger phase delay, ϕB, in element 3 to the "best" value. Examples of such "best" phase values for different size squares are shown in the Table 15.

It turns out that the calculated gain figures for the smaller arrays are actually slightly larger than the gain for the larger squares, but as a practical matter this fact is probably offset by the larger (reactive) currents required for radiation. The larger currents are necessary because of the mutual coupling and phase relations between elements and the required phase relationships; in practice with the inefficiencies usually caused by ground currents when using vertical antennas, the gain differences for the various squares are probably inconsequential. The patterns for all cases are quite good, but the best pattern is obtained for the $\lambda/4$ square. Incidentally, the 0.167λ and 0.33λ square allows the possibility that a single square can be used for two amateur bands, and this has indeed become the subject of a practical antenna system.[1]

Conclusion

Computer trial runs, through a program developed by WA2VBW, have facilitated the investigation of a large number of $\lambda/4$ vertical antenna-array configurations. "Best" configurations, drive conditions, power gains and patterns have been found for the cases of two, three and four elements. Especially interesting is the case of four elements arranged in a square whose side dimension is about one-quarter wavelength.

Cases using more than 4 elements have been investigated, but the complexity, probable cost, and difficulty of installation of such configurations, reduces their utility and so they will not be reported here.

The author wishes to acknowledge the contribution of Henry Hurwitz, WA2VBW, who supplied the original computer program for this investigation. This material was originally presented in *QST* by James L. Lawson, W2PV.

References

[1]Lawson, W2PV, "75/80 Meter Vertical Antenna Square Array," *QST*, March 1971.

360-Degree Steerable Vertical Phased Arrays

Microwave power-splitting and phasing techniques were applied to the design of this 80-meter array. It has established an outstanding record for performance on long and difficult paths.

The possibility of providing effective 360-degree horizontal coverage with an array switched electrically, rather than rotated mechanically, has long intrigued many designers. Such a solution to the directional antenna problem is of particular interest to amateurs operating on the lower frequencies, where any mechanical rotation system is difficult and expensive to build. One of the authors, now W1CF, writing under his old call, W1HKK, described an 80-meter switchable phased array of four quarter-wave in-line elements more than 10 years ago.[1] The present article describes several novel array designs, using up-to-date technology, which provide greatly improved operation. Also covered are techniques used for effective power division, the beam-forming phasing system, switching, and impedance matching. Ground radials, cable and connector selection, and dc continuity testing are discussed.

One of these arrays recently constructed for 80-meter use has a single 97-degree lobe with a gain over a single vertical of approximately 7 dB at low angles. Its front-to-back ratio is 25 dB, and its front-to-side ratio is more that 12 dB, over the whole 80-meter band. It is switchable over 360 degrees in four 90-degree steps.

Computer-Modeled Arrays and Patterns

In the spring of 1975, while sitting over a cup of coffee, the three authors discussed the possibility of rebuilding the 1965 4-

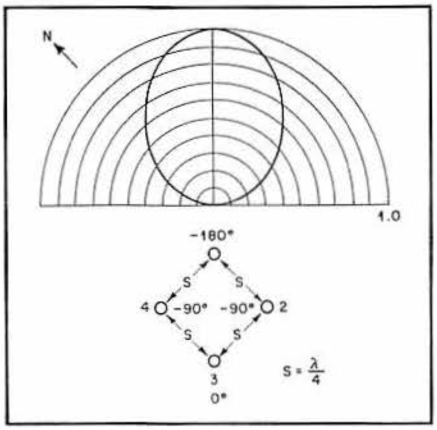


Fig. 29 — Polar plot of relative power, and planar view of the four-element diamond array showing the pattern obtained with no dc voltage on the switching relays, as in Fig. 31. Minor lobes are too far down to show on this scale.

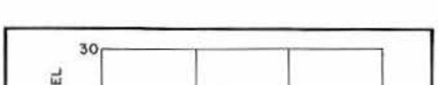


Fig. 30 — Bandwidth and side-lobe study of the four-element diamond array.

element array, using many improvements in technology that have evolved in the last 10 years. Dr. Joseph White accelerated the effort by coming up with a computer program written in Fortran IV, called ARRAY, which allows the user to plot patterns of arrays of from 2 to 99 elements in various spacings and combinations of phase and power, without ever leaving the computer terminal. Over 30 iterations using 4 elements were explored, and the computer-printed polar plots and other gain data analyzed, before we arrived at a configuration which provided good forward gain over a broad beamwidth, with no measurable unwanted lobes.

The configuration selected has four quarter-wavelength vertical elements in a square, with quarter-wave spacing between adjacent elements, as shown, with its predicted pattern, in Fig. 29. All elements are fed with equal amplitudes, the rear element at 0°, the two side elements at -90° and the lead element at -180°. The beam is transmitted along the diagonal from the rear to lead element. Gain due to horizontal beam formation alone is about 5.3 dB over a single vertical element. Front-to-back ratio is 25 dB. Front-to-side ratio is 12 dB, at 90° either side, increasing to much higher levels at 135° either side. Since most of the vertical energy is concentrated at low angles by the array, as much as 4 dB of gain additional to the predicted 5.3 dB in the horizontal plane can be achieved in theory, with perfectly conducting ground. The authors estimate that a good radial system and less-than-perfect ground yield an additional gain of 2 dB, or a total gain just over 7 dB for the system described.

The computer predicts a half-power beamwidth of 97°, so a suitable switching matrix can be used to direct the beam to four different quadrants, with only a slight loss of forward gain at the cross-over points, and virtually no deterioration of the front-to-back and front-to-side suppression. A computer study of the effect of variations in element spacing on forward-gain to maximum side-lobe level, plotted in Fig. 30, led to selection of $\lambda/4$ spacing of the corners of the square array. The 80-meter beam erected according to the computer-synthesized array design has proven to be remarkably successful. On-the-air results clearly approximate the performance anticipated by the program.

RF Power Dividers

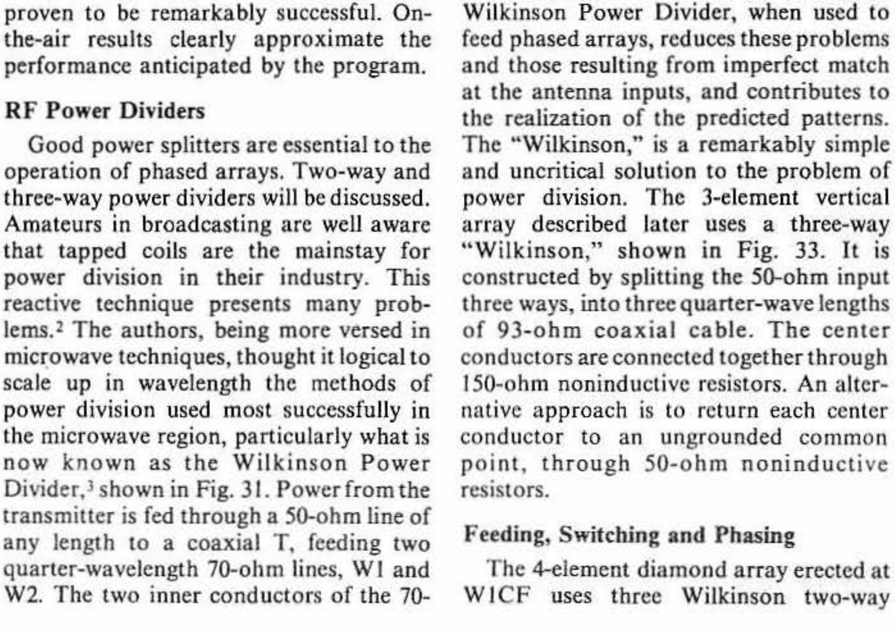
Good power splitters are essential to the operation of phased arrays. Two-way and three-way power dividers will be discussed. Amateurs in broadcasting are well aware that tapped coils are the mainstay for power division in their industry. This reactive technique presents many problems.[2] The authors, being more versed in microwave techniques, thought it logical to scale up in wavelength the methods of power division used most successfully in the microwave region, particularly what is now known as the Wilkinson Power Divider,[3] shown in Fig. 31. Power from the transmitter is fed through a 50-ohm line of any length to a coaxial T, feeding two quarter-wavelength 70-ohm lines, W1 and W2. The two inner conductors of the 70-ohm lines are connected through a 100-ohm noninductive resistor, R1. This type of divider gives an equal power split, matches to 50-ohm loads at the two outputs, and has the unique property that any energy returning to the two outputs out of phase, due to mismatches or mutuals, is absorbed in the 100-ohm resistor.

The 90-degree phase-delay cable (DL) used in one side of each of the three power-splitting hybrids serves to assure that equal power reflections from the antennas are absorbed. Theoretically the resistors absorb none of the forward power. This technique provides approximately 30 dB of isolation from one output terminal to the other, to unwanted energy.

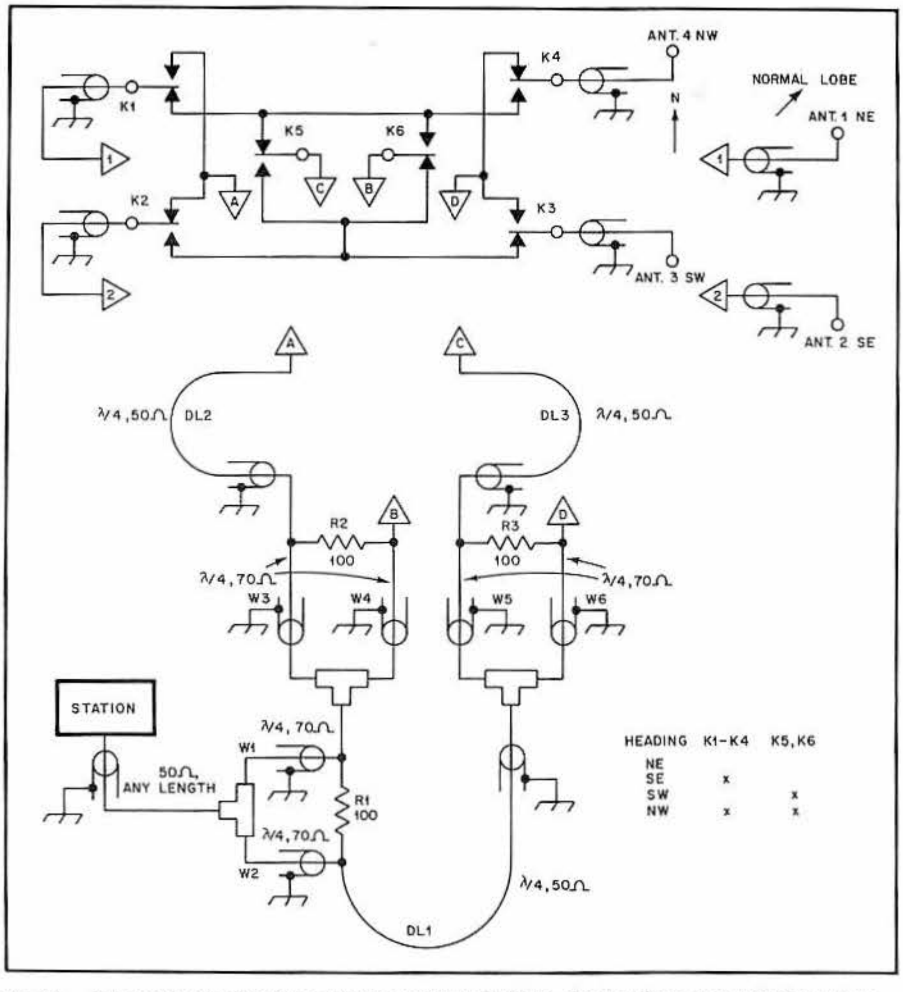
Reference is made in the 1965 article to difficulty in adjusting a phased array, because of element interaction due to mutual impedances between elements. The Wilkinson Power Divider, when used to feed phased arrays, reduces these problems and those resulting from imperfect match at the antenna inputs, and contributes to the realization of the predicted patterns. The "Wilkinson," is a remarkably simple and uncritical solution to the problem of power division. The 3-element vertical array described later uses a three-way "Wilkinson," shown in Fig. 33. It is constructed by splitting the 50-ohm input three ways, into three quarter-wave lengths of 93-ohm coaxial cable. The center conductors are connected together through 150-ohm noninductive resistors. An alternative approach is to return each center conductor to an ungrounded common point, through 50-ohm noninductive resistors.

Feeding, Switching and Phasing

The 4-element diamond array erected at W1CF uses three Wilkinson two-way



Terminations and switching relays at the center of W1CF array.



HEADING	K1-K4	K5, K6
NE		
SE	x	
SW		x
NW	x	x

Fig. 31 — Schematic diagram of the Wilkinson Power Dividers, phasing lines, and switching relays (rf connections) for the four-element array. Dc switching commands for the four pattern headings are given at the lower right.

power dividers, as shown in Fig. 31. Phasing is accomplished with three 90-degree sections of RG-8/U cable, DL1, DL2, DL3. The four outputs are at 0°, -90°, -90° and -180° respectively in phase relationship, with power from the transmitter divided into four equal parts. Every effort was made to preserve symmetry throughout the system, in the hybrids, phase shifters, rf switching, feeds, and antenna placement, in order to have the array perform uniformly as it is switched between the four headings.

The switching can be done with six spdt coaxial relays, as in Fig. 31, or with one transfer relay and four spdt relays. With no voltage on the relay coils, the arms are in the positions shown in Fig. 31, giving northeasterly directivity (57° true, on Paris) the heading used most of the time at W1CF. The array is about 500 feet (152.40 m) from the transmitter, necessitating use of remote relays. A prospective user should consider the tradeoff between cable and relay costs. If the array is close to the station, four equal lengths of 50-ohm line can be brought into the station, and the switching done with a 4-pole, 4-position switch.

The long run of line here was dictated by the desire to take advantage of ground qualities and concealment afforded by swampland 500 feet (152.4 m) from the house. Not wanting to be electrocuted, we used 28 volts dc for operation of the switching relays. By judicious use of binary arithmetic, the switching commands require only three wires. Selection of the four beam headings is done at the operating position with a 4-wafer, 4-position switch. Relays should be selected for reliability and ease of weatherproofing. The cluster of relays and teminations shown in the photograph is at the geometrical center of the W1CF array. The connectors are protected against moisture by 3/4-inch (19 mm) heat-shrink tubing, which should extend from the bottom half inch (13 mm) of the connector 2 inches (51 mm) down the cable. In addition, wide plastic wastebaskets are used to protect these components. The expensive precautions were taken as the result of hard experience with moisture in the cables and connectors in the 1965 array.

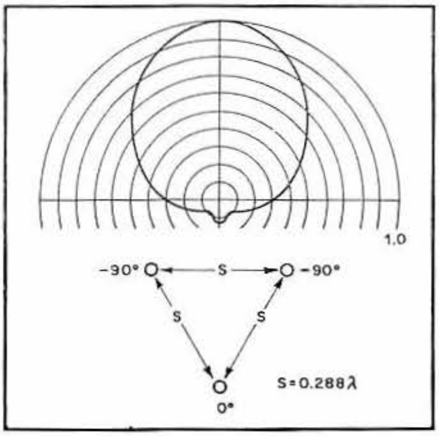


Fig. 32 — Polar plot of relative power, and planar view of the three-element triangular array.

Radiators and Radials

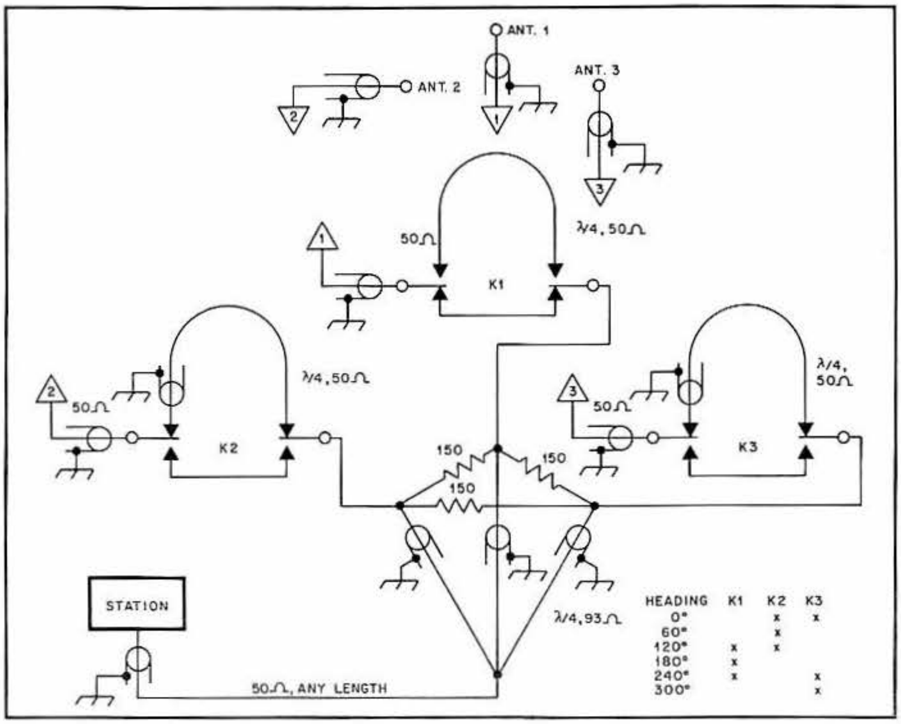
Relays K1 through K4 (Fig. 31) connect to their respective radiators through equal lengths of 50-ohm line, with no special attempt made for matching. The radiators are 57.5 feet (17.53 m) tall, above the base insulators. Constructional details follow the 1965 article, except as outlined below. Base insulators are 2-inch (51-mm) ID PVC pipe, 1/4 inch (6-mm) wall, 18 inches (457 mm) long, affixed to the aluminum with PVC cement and self-tapping screws. Each radiator is guyed at three levels with 3/16-inch (5-mm) galvanized cable, broken every 30 feet (9.14 m) with egg insulators.

Though 120 radials are considered to be the optimum number, only 40 per element are used here. Most are 65 feet (19.81 m) long, no. 12 galvanized wire, lying directly on the ground. This presents no hazard, as there is no foot traffic through the swamp area. The center radials are interconnected to two common busses in the central region, as recommended in reference 2. The authors feel intuitively that the square geometry of the array, in addition to providing considerable symmetry of the mutuals, allows a higher packing density for the radials, reducing ground losses.

Though the array has quarter-wavelength elements, all the feedpoints are at 50 ohms, and any type of vertical element can be used, provided an effort is made to match the inputs, and networks used for matching are *the same for all 4 elements.* Obviously, a height of 5/8 wavelength would be desirable, particularly for arrays built for higher frequencies. An indication of match would be to put rf voltmeters across the 100-ohm resistors, and tune the matching networks simultaneously for minimum voltage across the resistors. A nice thing about the λ/4 case is that the match is close enough that this step has not been necessary.

Testing

Before the array is fired up somebody should go to each element and short the input, while another person watches an ohmmeter placed across the main line at the station end. Make sure that a very low dc resistance is measured. Then, with the array in the normal position, as in Fig. 31, make sure that the resistance across the



HEADING	K1	K2	K3
0°		x	x
60°		x	
120°	x	x	
180°	x		
240°	x		x
300°			x

Fig. 33 — Schematic diagram of a three-element vertical array and its directivity switching and power dividing circuitry. Interconnecting leads should be as short and symmetrical as possible. The 50-ohm lines between the relays and antenna elements should be all the same length.

input is high. If it is low, check for moisture in the cables or connectors or for other leakage resistance. Silicone grease in the connectors is a good moisture preventive measure. It is recommended that these resistance checks be repeated periodically to be sure that all is well.

When the array is ready for use, go easy at first, as any reflected energy will be dissipated in the 100-ohm resistors. If they become hot, better matching is necessary, and if they blow up, perhaps higher-wattage resistors are needed. At W1CF, resistor banks were made up of 6, 20-watt, 150-ohm surplus resistors in series-parallel to give 100 ohms. These handle the dissipated power when the system is driven from a 4CX1000A amplifier, and after a month of operation there was no evidence of resistor damage. No attempt should be made to hot-switch the directivity. This was done inadvertently, and the result was the need for extensive emergency repairs — in midwinter.

Performance

In the short time that the array has been in use, all continents have been worked on 80-meter phone, including several stations in Japan and India, tough paths from New England. Gain and side and back rejection on all signals except those arriving from very high angles are just what the computer program predicted.

In receiving in the "search" mode, one hand tunes the receiver while the other operates the lobe selector switch, to see which position "listens" best. The big W1CF rotary array for 10, 15 and 20 takes 45 seconds to rotate 360°, which tends to discourage frequent directional checks. With the phased array a complete scan takes but a few seconds. The high front and side rejection eliminates most of the interference from signals in unwanted directions, and in transmitting the clean patterns help to prevent ruffled feathers.

A surprising by-product has been the reduced atmospheric noise pickup from unwanted directions. In particular, when listening toward Europe atmospheric noise coming from electrical storms in the southwest is greatly reduced, improving the signal-to-noise ratio on signals arriving from across the pond. The array is an order of magnitude better on both transmitting and receiving than any antenna previously used on 80 at W1CF. It has more than held its own with the competition, in all four quadrants. Of special interest to operators who like to use both phone and cw on 80 is the fact that the SWR is close to unity, from 3.5 to 4 MHz.

Triangle 3-Element Array

Anticipating that some amateurs may wish to use three rather than four elements, the ARRAY program was used to explore equilateral triangle configurations. Though it was not reduced to practice, a 3-element vertical array with 0.288λ spacing between adjacent radiators looks promising. The lead element is driven at 0° and the two side elements at -90°. The forward lobe is 135° wide, with a gain of close to 5.5 dB, including an estimated 1 dB contributed by vertical focusing. Front-to-back ratio is 12 dB. With suitable switching, the pattern can be aimed in six different directions, again providing 360-degree coverage. The three-way Wilkinson mentioned earlier must be used with three 90-degree sections of 50-ohm line, to provide the proper phase relationships. Several other configurations appear promising, but involve more complex switching and power-dividing circuitry.

Applications for Other Frequencies

The diamond and triangle antenna configurations may find uses at other frequencies, as was done with the 1965 design.[4] Formulas are given below for determining the line lengths and element spacings. A 2-meter phased array can be mounted on the roof of a car and wafer-switched to the desired directions. For people who like to experiment with logic and rf switching with semiconductors, circuits can be devised so that the receiver can scan periodically, and the antenna steered to the desired signal.

The authors wish to thank the many people who have contributed to the success of this project, including W1FRR, K1GXT, W1HMV, W1FXT, K1CCK, M. E. Hines, F. Howe, H. Wells, R. Rearwin, H. P. Scott, and many others. We also wish to thank Microwaves Associates, Inc., for the use of their superb computer facilities.

Formulas for length of quarter-wave (90°) phasing lines, and spacing of radiators, are given below:

Electrical λ/4, solid-dielectric coaxial line, 50 or 70 ohms (RG-8, -11, -58, -59):

$$L_{ft} = \frac{162.36}{f_{MHz}}$$

Electrical λ/4, solid-dielectric coaxial line, 93 ohms (RG-62, -71):

$$L_{ft} = \frac{206.64}{f_{MHz}}$$

300-ohm Twin-Lead — parallel three λ/4 sections to approximate 93-ohm cable (requires 1 input and 3 output 1:1 baluns):

$$L_{ft} = \frac{201.72}{f_{MHz}}$$

Radiator spacing, diamond array:

$$S_{ft} = \frac{246}{f_{MHz}} > 0.25\lambda$$

Radiator spacing, triangular array:

$$S_{ft} = \frac{283.4}{f_{MHz}} > 0.288\ \lambda$$

This material was originally presented in *QST* by Dana W. Atchley, Jr., W1CF, Harold E. Stinehelfer and Joseph F. White, Ph.D.

References

[1] Atchley, "Switchable 4-Element 80-Meter Phased Array," *QST*, March 1965.
[2] National Association of Broadcasters, *Engineering Handbook*, 6th Edition.
[3] Wilkinson, "An N-Way Hybrid Power Divider," *IRE Transactions on Microwave Theory and Techniques*, January 1960.
[4] Botts, "A Four-Element Vertical Beam for 40/15 Meters," *QST*, June 1975.

An Etched-Circuit Monimatch for Checking Your Antenna System

Why buy an expensive SWR indicator when you can build this slick little unit at home? Not only will you save money, but you'll learn something about how SWR meters operate. Try the W1ICP circuit — you'll like it!

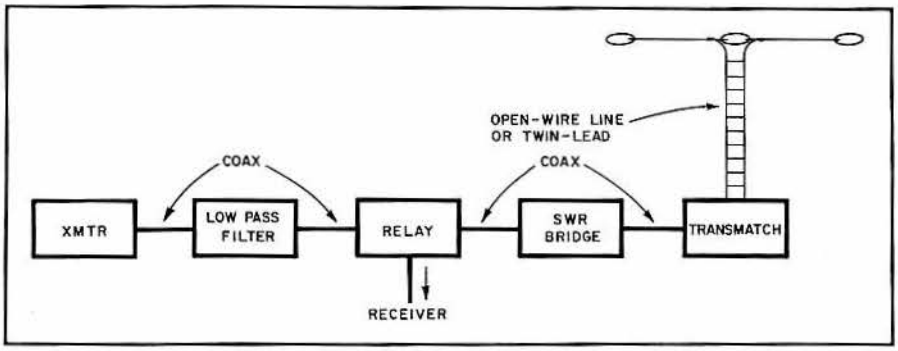


Fig. 34 — A typical setup for using a Monimatch in a multiband antenna system using a single dipole. The length of the dipole is not critical but it should be at least 1/4 wavelength overall at the lowest operating frequency for good efficiency. The feed line can be any length. The antenna relay and low-pass filter may be omitted if not needed.

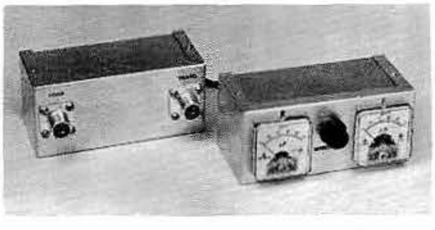
A Novice who reads the instruction manual that comes with his transmitter and uses a 50-ohm dummy antenna can follow the tune-up procedures fairly accurately. With the dummy antenna he will find that the settings for the tuning controls will be fairly close to those specified by the manufacturer. However, when an antenna system is attached to the rig, in many instances the adjustments are far removed from any "book" setting. When this happens the Novice finds that he cannot get proper tuning of the rig, or worse yet, actually damages the equipment by trying to "force" it to work.

Nearly every transmitter these days, whether commercial or home-built, has a final amplifier stage that is designed to work into a 50-ohm load. If the load is something other than 50 ohms it may be impossible to tune the amplifier stage correctly. Of course, an important part of the problem is finding out what the load is — or, rather, how far from 50 ohms it happens to be. The piece of measuring gear described in this article is a device for doing just this. However, before describing the Monimatch and what it can do, let's take a little closer look at antenna-system loads.

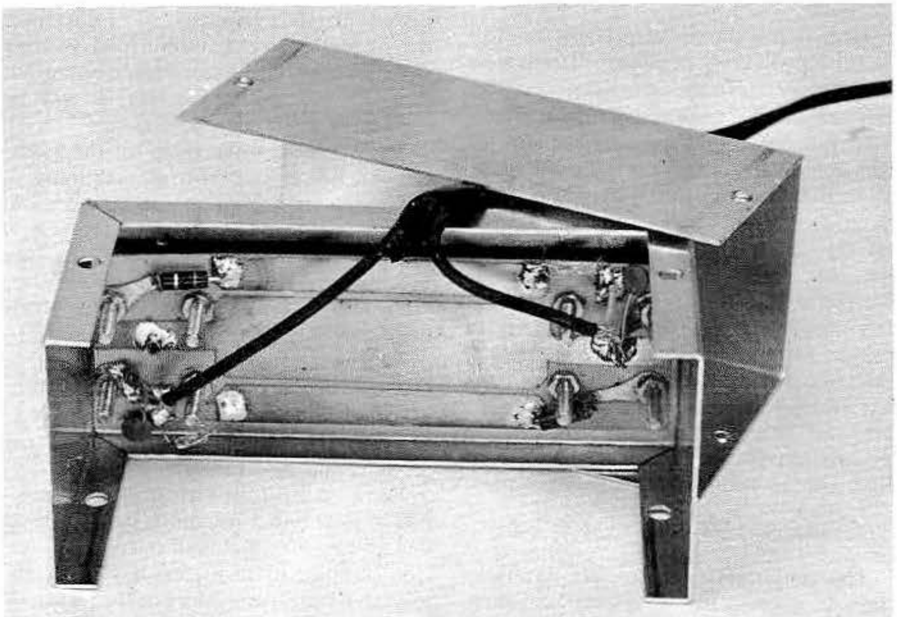
The "50-Ohm" Load

The evolution of transmitter design since WW II has been influenced by several factors that have led to design that is more or less standard these days. First off, television came along right after the war and the hams quickly discovered that extremely tight shielding of a transmitter was needed to prevent undesired radiation that could cause TVI. However, when tight shielding was installed, band changing without band-switching became a real chore because there were so doggone many screws to unscrew and rescrew.

The one type of tank circuit that lent itself very well to the problem was the pi network. It was a fairly simple job to design a tightly shielded bandswitching transmitter, using the pi network, that would work into a 50-ohm load. Why 50 ohms? Simply because at this time 50-ohm coaxial cable had become a very popular type of transmission line. During the war, techniques were developed that made the manufacture of flexible coaxial cable a



Here is the completed Monimatch with the two meters and the sensitivity control in the box at the right. The sensing unit is at the left.



This is the sensing unit of the etched circuit Monimatch. As pointed out in the text, be sure to use a heat sink when soldering the diodes and resistors to the circuit board. The two shielded pickup leads are routed out the back of the Minibox, through a rubber grommet.

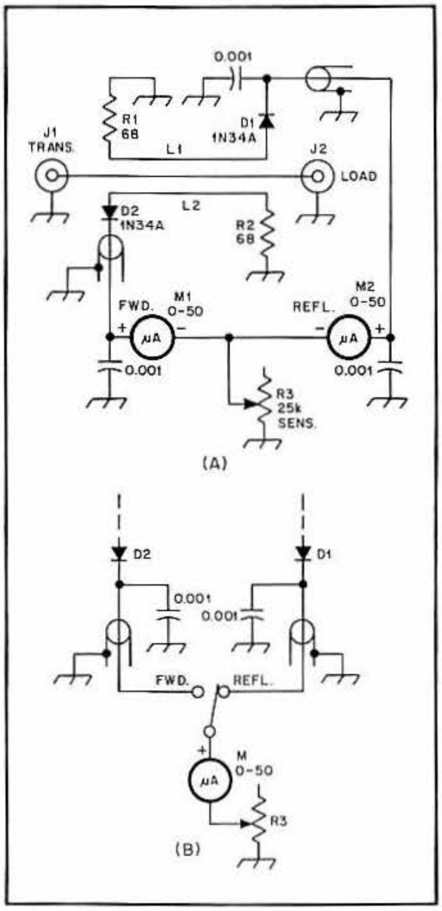


Fig. 35 — Circuit details of the etched-circuit Monimatch. The 0.001 μF capacitors are disk ceramic.
D1, D2 — 1N34A germanium diodes.
J1, J2 — Coax chassis fittings, type SO-239.
L1, L2 — See text and Fig. 36.
M1, M2 — 0-50 μA meter (Lafayette 99 H 5049).
R1, R2 — 68-ohm, 1/2-watt carbon or composition.
R3 — 25 kΩ control, linear taper.
S1 — Spdt switch.

reliable and economical process. So TVI and the availability of coax feed lines were the primary contributing factors that led to our present-day transmitter design.

If the load that is attached to the transmitter is something other than 50 ohms then the transmitter may be difficult to load, depending on a couple of other factors. While it is possible to design a pi network that will handle quite a wide variety of loads, many present day manufacturers, in order to compete in given price ranges, use a minimum number of parts in the tank circuit of the amplifier. For such rigs to operate properly the load must be between 25 and 75 ohms. This of course means that the user *must* furnish a load that will fall within this range.

Transmission Lines

The output terminal on all rigs these days is a coax fitting, which of course implies that a coaxial line must be attached to the rig. This doesn't mean that the coaxial line has to go all the way to the antenna. It could be connected to a Transmatch or a balun. What is important is that the first thing in the antenna system is the coaxial line that is attached to the rig.

Many Novices mistakenly believe that if you attach a 50-ohm coaxial cable to rig you *automatically* have a 50-ohm load. This is not true. The 50-ohm designation on the cable merely means that 50 ohms is the *characteristic impedance* of the cable. The characteristic impedance of a transmission line is determined by the size of the conductors used, the spacing of the conductors, and the dielectric material used to separate and support the conductors. The only time you would have a 50-ohm load using 50-ohm cable is when the line is terminated in its characteristic impedance. In other words, if the antenna has an impedance of 50 ohms then you will have a 50-ohm load on the rig. If the antenna has an impedance of other than 50 ohms then the load at the transmitter will be something other than 50 ohms. This in turn leads us up to a short discussion of standing-wave ratio.

SWR

If a transmission line is terminated in its characteristic impedance, all the power fed into the line from the transmitter will be delivered to the load end — in this case, the antenna. Actually, not quite all the power will reach the antenna because there is always some loss in the transmission line itself. However, what is important is that when the line is terminated in its characteristic impedance none of the power that reaches the end is reflected back toward the transmitter; all of it is used up in the antenna.

When the antenna impedance is different from the line impedance some of the power will be reflected back toward the transmitter end. Standing waves of voltages and currents will then exist on the transmission line. When this happens, the transmitter will no longer "see" a 50-ohm load. Exactly what the load will be will depend on several factors,[1] but suffice to say it will be something other than 50 ohms.

The standing-wave ratio on the transmission line is the ratio of maximum to minimum voltage or maximum to minimum current that exists along the line. If the line were matched in its characteristic impedance the voltage would be the same along the line and of course the SWR would be 1 to 1. The SWR is determined by dividing the resonant antenna impedance into the line impedance, or vice versa. For example, if the antenna impedance were 25 ohms and a 50-ohm line were used, the SWR would be 2 to 1.

For a moment, let's assume that regardless of how bad a mismatch exists, we are still able to tune and load our transmitter. The question then arises, how does the mismatch affect the losses in the transmission line? The answer to the question depends on how efficient the transmission line is.

Remember earlier we said there are always some power losses in every transmission line. If we have a mismatch at the antenna end, some of the power that reaches the end will be reflected back down the line. In traveling back, some of this power will be dissipated in the line, and the higher the SWR the higher these additional losses will be, because a higher SWR means that a greater proportion of the power will be reflected. In a transmission line that is 100 percent efficient (one that has no losses) it follows that regardless of how high an SWR exists, we wouldn't have any losses due to the SWR. Unfortunately, there "ain't no such" line, although some types of lines are much less lossy than others.

Also unfortunately, coaxial lines fall into the class that can be considered to be lossy lines. Just as an example, let's assume that you are using 100 feet (30.48 m) of RG-58/U on the Novice 15-meter band, and you are getting 50 watts out of your 75-watt Novice rig. This 50 watts is what is leaving your transmitter on the way to antenna via the 100 feet (30.48 m) of line. The loss for 100 feet (30.48 m) of RG-58/U at 21 MHz is 1.9 decibels. Translating this figure to power, we would lose about 20 of our 50 watts in the losses in the feed line, leaving only 30 watts to reach the antenna and be radiated. This is assuming the antenna impedance to be 50 ohms, the same as that of the line. If there is a mismatch the losses will be higher, as pointed out earlier. Suppose the SWR is 3 to 1, using the same setup. The *additional* loss in the system because of the SWR would be 1 dB, or a total of close to 3 dB. A 3-dB loss represents almost exactly one-half the power — that is, only 25 watts reach the antenna to be radiated. RG-8/U cable has the same characteristic impedance as RG-58/U but has less loss because it has larger conductors and more spacing between the conductors (and of course is more expensive).

The closest thing to a lossless transmission line is open-wire line. An open wire line on 21 MHz has only 0.08 dB loss per 100 feet (30.48 m). Even with a very high mismatch — for example, an SWR of 20 to 1, the additional losses are still less than 1 db!

This should not be interpreted to mean that coax is an undesirable type of line to use. For beam antennas it is difficult to beat the ease and convenience of using coax. However, for a single antenna, such as a dipole that is to be used on all bands and all frequencies, the best system is one consisting of a Transmatch and a feed line of open-wire line, such as shown in Fig. 34. With this system you can forget about line losses, SWR on the line, and mismatches between the antenna and feed line. By correctly adjusting the Transmatch, you can always give your rig a 50-ohm load regardless of what the load is on the antenna side of the Transmatch. If we use an SWR bridge in the short length of 50-ohm coaxial line that connects the rig to the

Transmatch, we can adjust the Transmatch so that the 50-ohm line shows a match, or SWR of 1 to 1, and the transmitter always sees a 50-ohm load.

The SWR bridge in the photographs and drawings is simple to build, and when installed in 50-ohm cable, will show the relative mismatch in the line, and also will indicate when you get the Transmatch properly adjusted for a match. The SWR bridge can also be used as an output indicator, which is very handy when tuning up the rig.

SWR Bridge Circuit Details

The etched-circuit Monimatch shown here is a reflectometer that samples the forward and reflected voltage in a 50-ohm line. Fig. 35 shows the circuit diagram. L1 and L2 are the pickup lines. In operation, a very small amount of power is coupled into the pickup lines and the rf voltages are rectified by D1 and D2. The rectified voltages are then fed to the two meters, M1 and M2, and the SWR then determined from the readings.

While a Monimatch is not a precise piece of measuring equipment, the SWR readings will be close enough for practical purposes. In order to determine the SWR, the forward-reading meter is set to full scale by adjusting R3, the sensitivity control, and then the reading on the "reflected" meter is noted. The formula for the SWR using this system is

$$\frac{F + R}{F - R}.$$

For example, let's assume the "reflected" reading is 5, with the "forward" reading being 10. Then 15 divided by 5 (that is, 10 + 5 divided by 10 − 5) would mean the SWR is 3 to 1. The closer the "reflected" reading is to zero, versus full-scale reading on "forward," the closer you come to 1 to 1, or a matched condition.

In the unit shown, two meters are used, one for the forward and the second for the reflected reading. However, if desired a single meter can be used and switched as shown in Fig. 35 at B. We used two meters in the indicator as this permits constant monitoring of what is happening in the line. The meters are inexpensive ones made in Japan.

Construction Details

Fig. 36 is a full-sized template of the etched circuit board. A *QST* article[2] went into detail showing simple methods for making etched circuits, so we won't treat the process here. In making this board, it is suggested that the board be covered with masking tape and then the pattern of Fig. 36 transferred to the tape. Using a sharp knife edge or razor blade and a straight edge, the masking tape can be carefully and accurately cut to the pattern.

After the board is etched, it can be positioned in the Minibox over the chassis connector holes and the board can then be marked at the drilling points for the mounting holes and the center conductor pins of the coax fittings. When installing the mounting screws, be sure they don't short to the center — conductor portion of the foil on the board.

There are a couple of other construction points that should be stressed. The lead lengths on R1 and R2 should be kept as short as possible. Also, be sure to use carbon or composition resistors, *not* wire-wound. When mounting the resistor and diode ends to the pickup sections, L1 and L2, the connections should be at the very ends of the sections. Also, use a heat sink when soldering the leads on any of the components mounted on the board, as too much heat from the iron can ruin the component.

The Monimatch and meters are mounted in separate Miniboxes, 2-1/4 × 2-1/4 × 5 inches (57 mm × 57 mm × 127 mm). The two connectors on the Monimatch sensing unit, J1 and J2, are mounted with their center pins 3-3/4 inches (95 mm) apart, center-to-center. In order to avoid an impedance "bump" in the feed line when the bridge is inserted in the line, the circuit board should be mounted 1/4 inch (6 mm) above the base of the Minibox. Quarter-inch (6 mm) spacers can be used under the circuit board at the screws holding both the board and the coax fittings to position the board accurately.

Shielded conductors should be used for the connections from the diodes to the meter enclosure. The shields should be grounded to the chassis at both boxes. These lead lengths are not critical, and the Monimatch can be remote from the meter indicator.

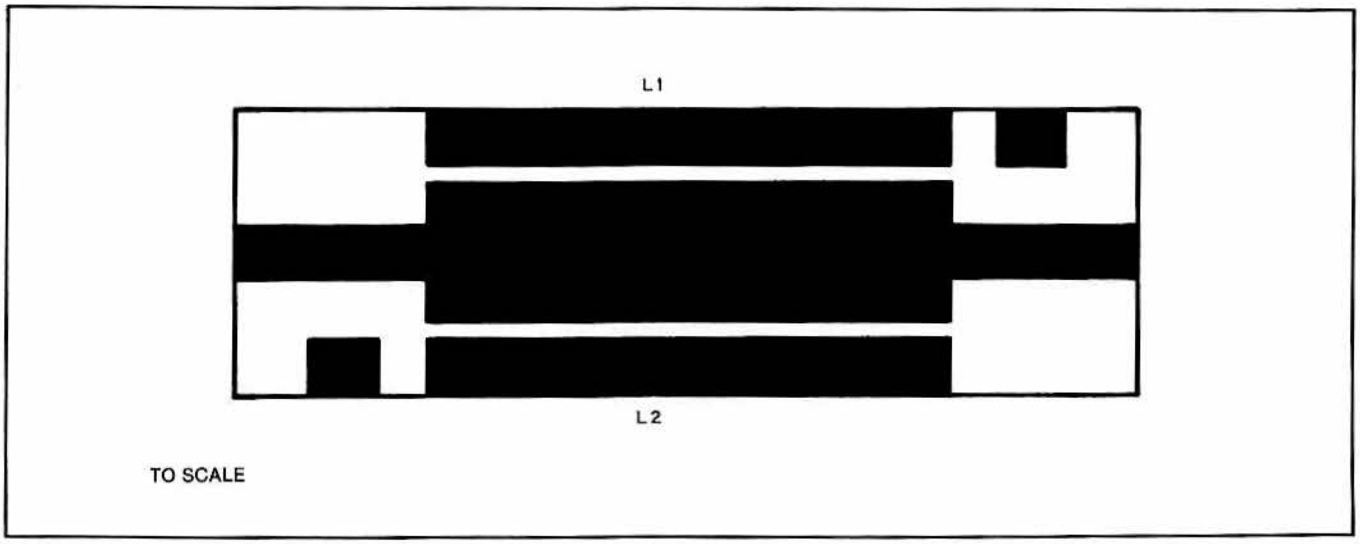


Fig. 36 — Etched circuit board template. The foil side is shown; the etched portion is shaded.

Using the Bridge

If you are using coax feed from the rig to the antenna, the bridge can be installed at any convenient spot in the line. If you are using a Transmatch, similar to the system as shown in Fig. 34, the Monimatch should be installed on the transmitter side of the Transmatch. Any relays or filters should be installed between the bridge and the transmitter, as shown.

Set R3 so that the arm of the control is at the top of the resistance — in other words, with all the resistance in series with the meter circuit. Tune up your rig in the normal fashion, and once tuned up adjust the sensitivity of the "forward" meter by moving the arm of R3 until the meter reads full scale. You can then determine the SWR by the formula mentioned earlier.

When adjusting a Transmatch, feed just enough power through the system to obtain about half-scale reading on the "forward" meter and then adjust the Transmatch controls for a match, as indicated by zero reflected power. You may have to adjust R3 as you adjust the Transmatch to keep the "forward" meter from reading more than full scale. Once you have the Transmatch adjusted for a 1-to-1 ratio as indicated by the bridge, the transmitter can be loaded up in the normal manner. We usually reduce the forward reading to about half scale, and then tune the rig for maximum output, as indicated by the meter. When doing this, you may notice that maximum output as indicated by the bridge meter occurs at some setting other than the normal transmitter plate meter "dip" reading. (Normally, the instruction manuals tell you to tune for a plate dip if the transmitter has no output meter.) However, the amplifier stage will work better if you tune for maximum output rather than the dip — keeping the plate loading within the transmitter ratings, of course.

Once you become familiar with the use of the bridge and interpreting the readings, you'll find it a very valuable device in your station. This material originally presented in *QST* by Lewis G. McCoy, W1ICP.

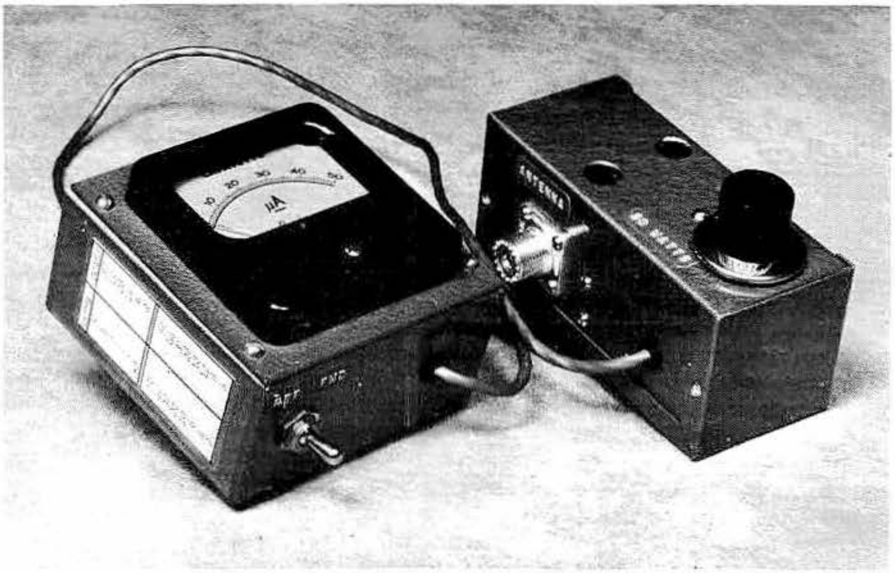
References

[1] [Editors Note: It is recommended that the newcomer obtain a copy of *The ARRL Antenna Book* for more detailed information on transmission line operation than can be provided in this article.]

[2] Schiebold, "Fast'n' Easy Printed Circuit Boards," *QST*, August 1969.

In-Line RF Power Metering

Problems are frequently encountered in designing and building reflected-power meters and SWR bridges. Examples of practical in-line rf wattmeters are given here, along with complete details for building a unit that will provide two power ranges, forward and reflected, for use from 3.5 to 30 MHz.



It is neither costly nor difficult to build an rf wattmeter. And, if the instrument is equipped with a few additional components it can be switched to read reflected power as well as forward power. With the foregoing feature the instrument can be used as an SWR meter for antenna matching and Transmatch adjustments.

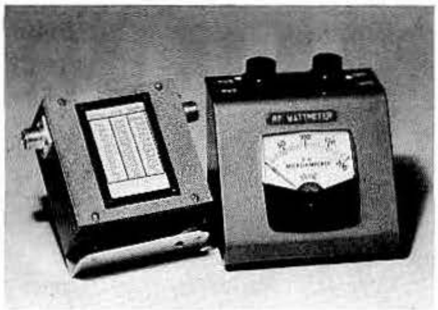
Perhaps the most difficult task faced by the constructor is that of calibrating the power meter for whatever wattage range he desires to have. The least difficult method is to use a commercial wattmeter as a standard. If one is not available, the power output of the test transmitter can be computed by means of an rf ammeter in series with a 50-ohm dummy load, using the standard formula, $P = I^2R$. Or, if one is not interested in obtaining power readings the bridge can be used solely as an SWR indicator, as is done with the Monimatch-style SWR bridge.[1]

The advantage of the circuits shown here over those of Monimatch bridges is that these instruments are not frequency-sensitive. Monimatch indicators become more sensitive as the operating frequency is increased, thus making it impractical to calibrate them in watts for more than one band, or for more than one portion of a given band. The units described here are more sensitive than Monimatches are. This makes it possible to calibrate them for power levels as low as 1 watt, full scale, in any part of the hf spectrum.

All of the circuits shown in this article are similar to the basic one which was described in *QST*.[2] Some of the circuits are those of commercial power meters, and are used to illustrate variations in the basic Bruene design. The reader may wish to experiment with some of these circuits.

Design Philosophy

Referring to the circuit of Fig. 37B, the circuit used by Collins Radio Company, the transmission-line center conductor passes through the center of a toroid core and becomes the primary of T1. The multi-turn winding on the core functions as the transformer secondary. Current flowing through the line-wire primary induces a voltage in the secondary which causes a current to flow through resistors R5 and R6. The voltage drops across these resistors are equal in amplitude, but 180 degrees out of phase with respect to common or ground. They are thus, for practical purposes, respectively in and out of phase with the line current. Capacitive voltage dividers, C3C7 and C4C8, are connected across the line to obtain equal-amplitude voltages *in* phase with the line voltage, the division ratio being adjusted so that these voltages match the voltage drops across R5 and R6 in amplitude. (As the current/voltage ratio in the line depends on the load, this can be done only for a particular value of load impedance. Load



values chosen for this standardization are pure resistances that match the characteristic impedance of the transmission line with which the bridge is to be used, usually 50 or 75 ohms.) Under these conditions, the voltages rectified by D1 and D2 represent, in the one case, the vector *sum* of the voltages caused by the line current and voltage, and in the other, the vector *difference*. With respect to the resistance for which the circuit has been set up, the sum is proportional to the forward component of a traveling wave such as occurs on a transmission line, and the difference is proportional to the reflected component.

The Collins circuit uses two 8-μF capacitors, C5 and C6, to permit the meter to approach the PEP level during ssb operation. The dc voltages in the forward and reflected lines charge the capacitors to permit a near-peak reading. The discharge rate is set by the series calibrating resistors, R1 through R4, and is dependent upon which of them is switched into the metering line at a given time. The circuit of Fig. 37B uses two 43-pF capacitors, C1 and C2, to cancel the inductive reactances of R5 and R6. Such reactance may become manifest at the high end of the range for which the instrument is built. If reactance is present in that part of the circuit the meter readings may not be accurate, especially at 10 and 15 meters. The capacitors were not needed in the circuit of Fig. 38, perhaps because the resistor leads were very short when they were mounted on the etched-circuit board.

Some Design Hints

It is important that the layout of any rf bridge be as symmetrical as possible if good balance is to be had. The circuit-board layout for the instrument of Fig. 38 meets this requirement. Also, the input and output parts of the equipment should be isolated from the remainder of the circuit so that only the sampling circuits feed voltage to the bridge. A shield across the end of the box which contains the input and output jacks, and the interconnecting line between them, is necessary. If stray rf gets into the bridge circuit it will be impossible to obtain a complete zero reflected-power reading on M1 even though a 1:1 SWR exists.

Referring again to Fig. 38, resistors R1 and R2 should be selected for the best null reading when adjusting the bridge into a resistive 50- or 75-ohm load. Normally the value will be somewhere between 10 and 47 ohms. The 10-ohm value worked well with the homemade instruments shown here. It was found that half-watt resistors exhibited somewhat less inductive reactance at 30 MHz than did some 1-watt units tried. R1 and R2 should be as closely matched in resistance as possible. They need not be exactly 10 ohms, so a VTVM can be used to match them. The resistors used for the circuit of Fig. 38 were actually 10.5 ohms each, and were chosen from an assortment of "10-percenters" on hand.

Silver-mica capacitors C3 and C4 were close enough in value so that special selection was not required. There should be enough leeway in the ranges of C1 and C2 to compensate for any difference in the values of the 330-pF capacitors. Ideally, however, C3 and C4 should be matched in value.

Diodes D1 and D2 should also be matched for best results. An ohmmeter can be used to select a pair of diodes whose forward dc resistances are within a couple of ohms of being the same. Similarly, the back resistances of the diodes can be matched. The matched diodes will help to assure equal meter readings when the bridge is reversed. (The bridge should be perfectly bilateral in its performance characteristics.) Germanium diodes are used in the bridges described here, but

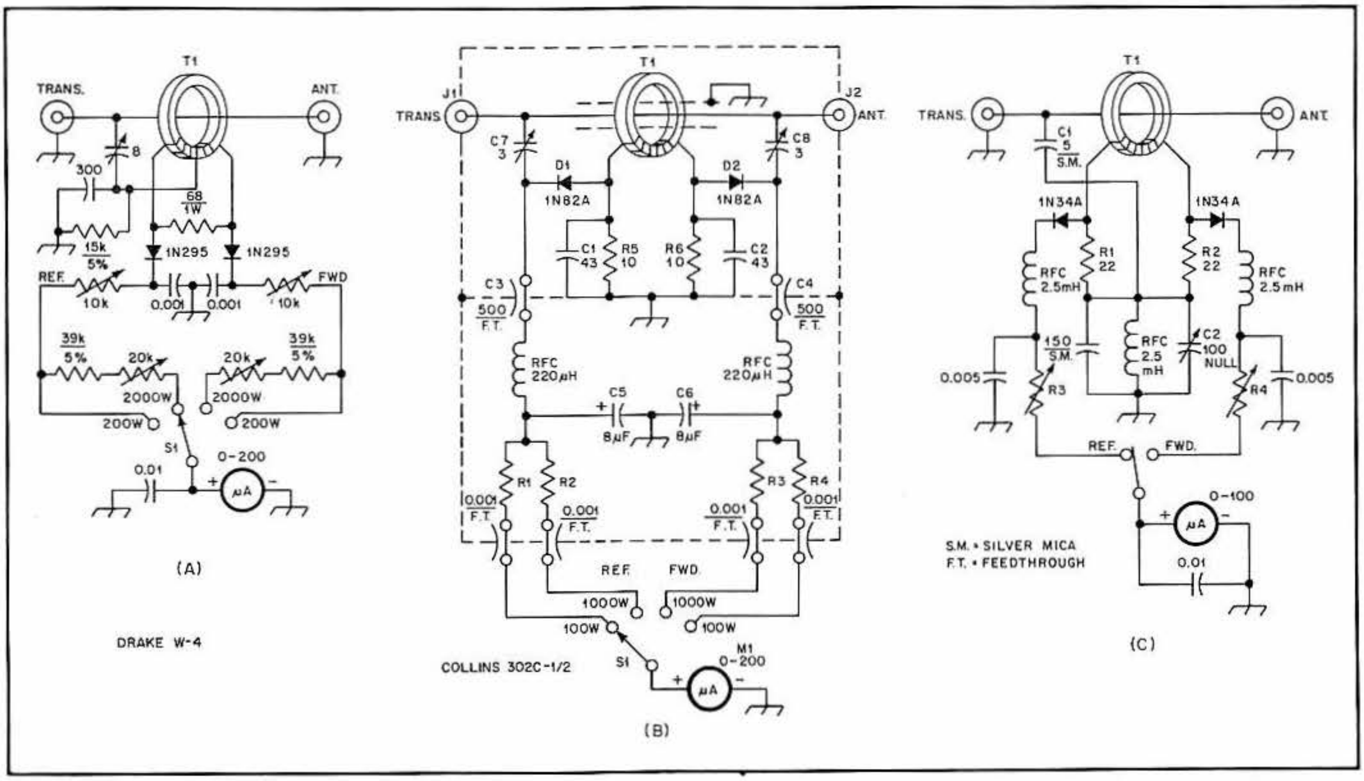
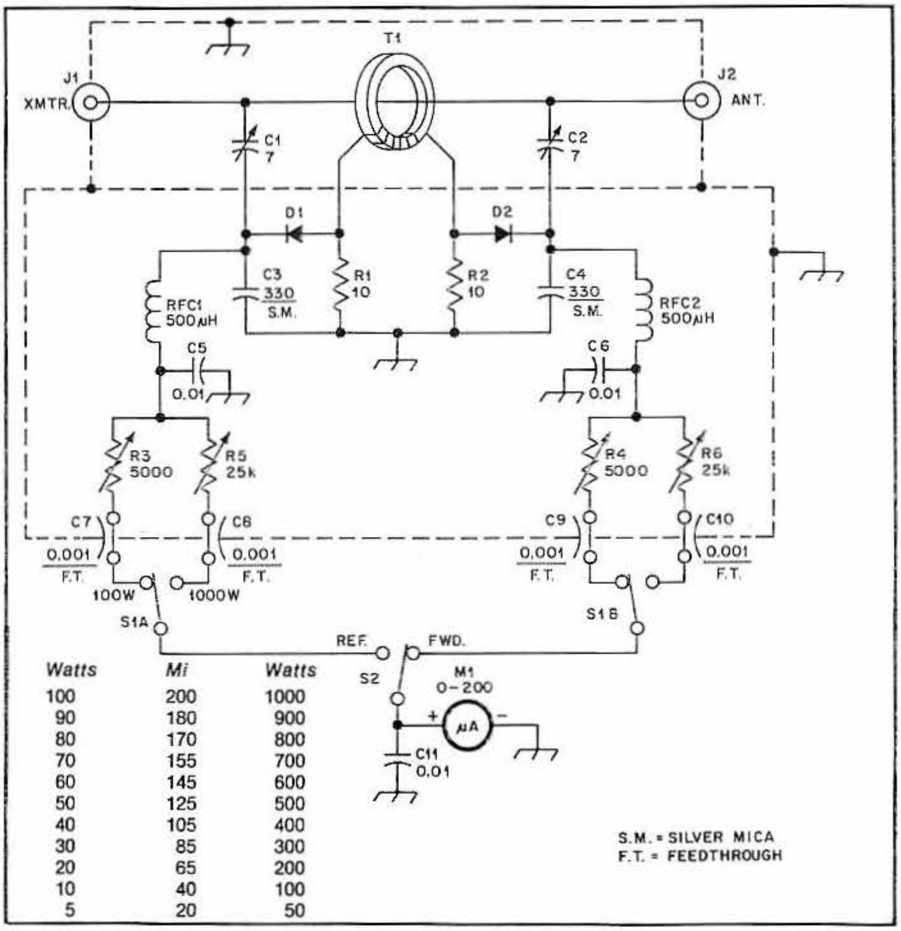


Fig. 37 — Schematic diagrams of typical in-line power meters. At A, the R. L. Drake W-4 instrument. It uses a center-tapped transformer at T1 and has but one capacitive voltage divider in the sensing circuit. The circuit at B is discussed in the text, and is used by Collins Radio Company. The capacitive voltage dividers in this circuit use two 500-pF feedthrough capacitors in place of the silver-mica capacitors specified in Fig. 38. Capacitors C5 and C6 permit a charge time that enables the meter to read near-peak power on ssb. Calibrating resistances R1 through R4 are factory selected. The circuit at C is similar to one used by Comdel in their power meter. In this circuit C1 is a fixed-value (small) capacitor, and the bridge is nulled by the larger capacitor in the divider, C2.



Watts	Mi	Watts
100	200	1000
90	180	900
80	170	800
70	155	700
60	145	600
50	125	500
40	105	400
30	85	300
20	65	200
10	40	100
5	20	50

Fig. 38 — Schematic diagram of a practical power wattmeter. A calibration scale for M1 is shown also. Fixed-value resistors are 1/2-watt composition. Fixed-value capacitors are disk ceramic unless otherwise noted. Decimal-value capacitances are in µF. Others are pF. Resistance is in ohms; k = 1000.

C1, C2 — 1.3- to 6.7-pF miniature trimmer (E. F. Johnson 189-502-4. Available from Newark Electronics, Chicago, IL).
C3-C11, incl. — Numbered for circuit-board identification.
D1, D2 — Small-signal germanium diode. IN34A, etc. (see text).
J1, J2 — Chassis-mount coax connector of builder's choice. Type SO-239 used here.
M1 — 0- to 200-µA meter (Triplett type 330-M used here.)
R1, R2 — Matched 10-ohm resistors (see text).
R3, R4 — 5000-ohm printed-circuit carbon control (IRC R502-B).
R5, R6 — 25,000-ohm printed-cirult carbon control (IRC R253-B).
RFC1, RFC2 — 500-µH rf choke (Millen 34300-500 or similar).
S1 — Dpdt single-section phenolic wafer switch (Mallory 3222J).
S2 — Spdt phenolic wafer switch (Centralab 1460).
T1 — Toroidal transformer; 35 turns of no. 26 enam. wire to cover entire core of Amidon T-68-2 toroid (Amidon Assoc., 12033 Otsego St., No. Hollywood, CA 91607).

silicon diodes can also be used. Silicon diodes conduct at a higher voltage than germanium diodes do — approximately 0.7 volt — and will not work too well in low-power wattmeters. Some silicon diodes were tried, but ceased to conduct at approximately 8 watts in the circuit of Fig. 38. This effect can cause misleading results when low values of reflected power are present during antenna adjustments. The SWR can appear to be zero when actually it isn't. The germanium diodes conduct at approximately 0.3 volt, making them more suitable for low-power readings.

Any meter whose full-scale reading is between 50 microamperes and 1 milliampere can be used at M1. The more sensitive the meter, the more difficult it will be to get an absolute reflected-power reading of zero. Some residual current will flow in the bridge circuit no matter how carefully the circuit is balanced, and a sensitive instrument will detect this current flow. Also, the more sensitive the meter, the larger will have to be the calibrating resistances, R3 through R6, to provide high-power readings. A 0- to 200-microampere meter represents a good compromise for power ranges between 100 and 2000 watts.

Construction

The power meter of Fig. 38 is built in two sections. The rf circuit and the calibrating resistors are housed in a 4 × 4 × 2-inch (102 × 102 × 51 mm) aluminum utility box. All components other than J1, J2, and the feedthrough capacitors, are assembled on the etched-circuit board.[3] Switches S1 and S2, and the meter, M1, are installed in a sloping-panel utility box which measures 5 × 4 inches (127 × 102 mm). Four-conductor shielded cable — the shield serving as the common lead — is used to join the two pieces. There is no reason why the entire instrument cannot be housed in one container, but it is sometimes awkward to have coaxial cables attach to a unit that occupies a prominent place in the operating position. Built as shown, the two-piece instrument permits the rf pickup head to be concealed behind the transmitter, while the control head can be mounted where it is accessible to the operator.

Toroidal transformer T1 fits into a cutout area on the circuit board. A 1-inch (25 mm) long section of RG-8/U cable — vinyl jacket and shield braid removed — provides a snug fit in the center hole of the toroid, and is used to complete the line between J1 and J2. The inner conductor of the RG-8/U section solders to the circuit board, thus holding T1 in place.

A flashing-copper shield divides T1 and its center-conductor line from the remainder of the circuit. This partition is shown in dotted lines in Fig. 38. It is mounted on the non-foil side of the circuit board and is secured at each end to solder lugs which are mounted under the retaining screws for J1 and J2.

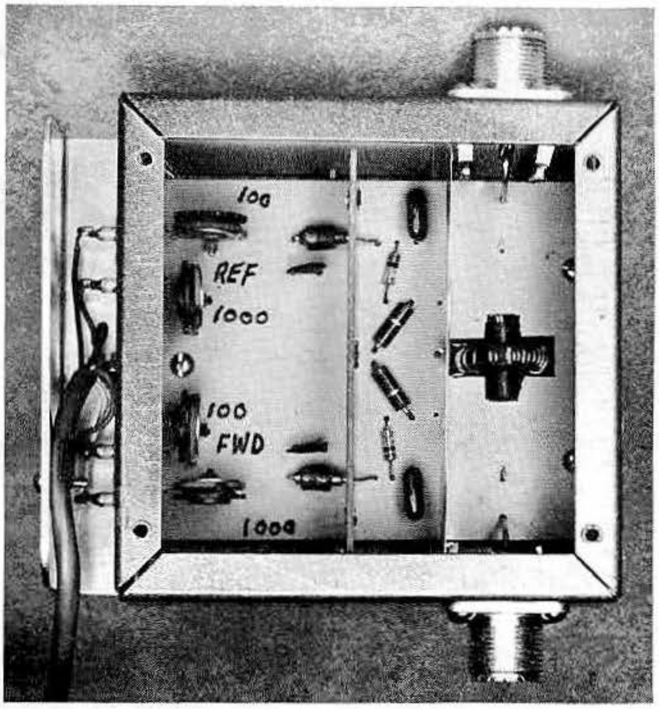
The circuit board is held in place, at the end near T1, by means of an aluminum L bracket. The circuit-board end nearest the feedthrough capacitors is held in place by a no. 6 spade bolt. A solder lug is mounted under the no. 6 nut (outside the case) which secures the spade bolt. The lug serves as a connection point for the common lead between the rf head and the control box. Two solder lugs are mounted under the bottom two retaining screws of each coax connector. The free ends of the lugs are soldered to the copper foil of the circuit board.

A partition is visible in the foil-side view of the rf head. It can be eliminated if desired, since it did not prove necessary when the unit was tested. Similarly, an extra shield partition is shown on the top side of the board. It too can be eliminated, for it turned out to be unnecessary. The flashing-copper shield discussed earlier is the only one required for the circuit of Fig. 38.

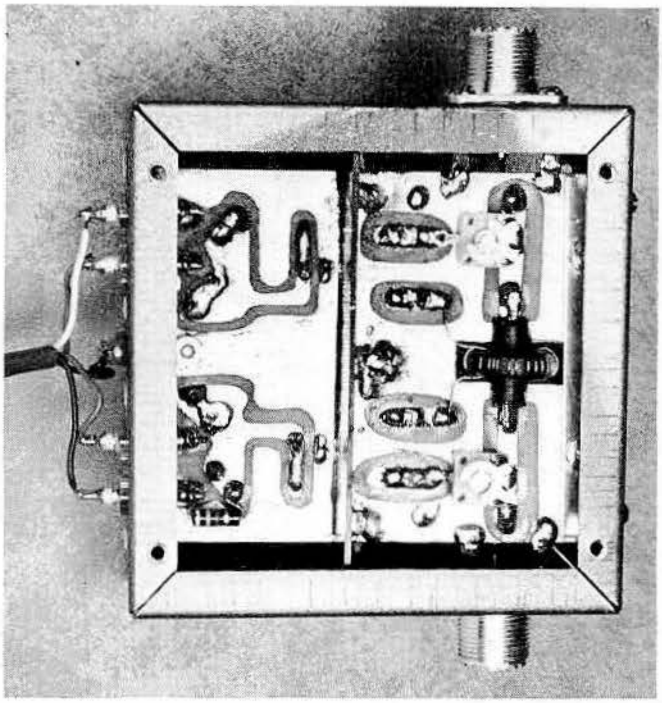
Checkout and Tune-up

Once the instrument is wired and ready to test it should be inspected for unwanted solder bridges between the circuit-board foils. It is usually a good idea to scrape out the rosin buildup between the foils, and this can be done with the blade of a small screwdriver. A continuity check for "opens" and "shorts" should also be made before power is applied to the unit. Make certain that the diodes are installed for the correct polarity — the banded ends (cathodes) toward C1 and C2.

Connect a noninductive 50-ohm dummy load to J2. A Heath Cantenna or similar load will serve nicely for adjustment purposes. Place S2 in the FORWARD position, and set S1 for the 100- range. An rf ammeter or calibrated power meter



Top view of the rf head for the circuit of Fig. 38. A flashing-copper shield isolates the through-line and T1 from the rest of the circuit. The second shield (thicker) is not required and can be eliminated from the circuit. If a 2000-watt scale is desired, fixed-value resistors of approximately 22 kΩ can be connected in series with high-range printed-circuit controls. Or, the 25 kΩ controls shown here can be replaced by 50 kΩ units.



Bottom view of the rf head for the circuit of Fig. 38. The fixed-value resistor at the lower left does not belong in the circuit, but was added as a shunt for one of the calibrating controls which was too high in value — a 50 kΩ unit that was on hand. The shield partition shown here proved unnecessary and can be eliminated.

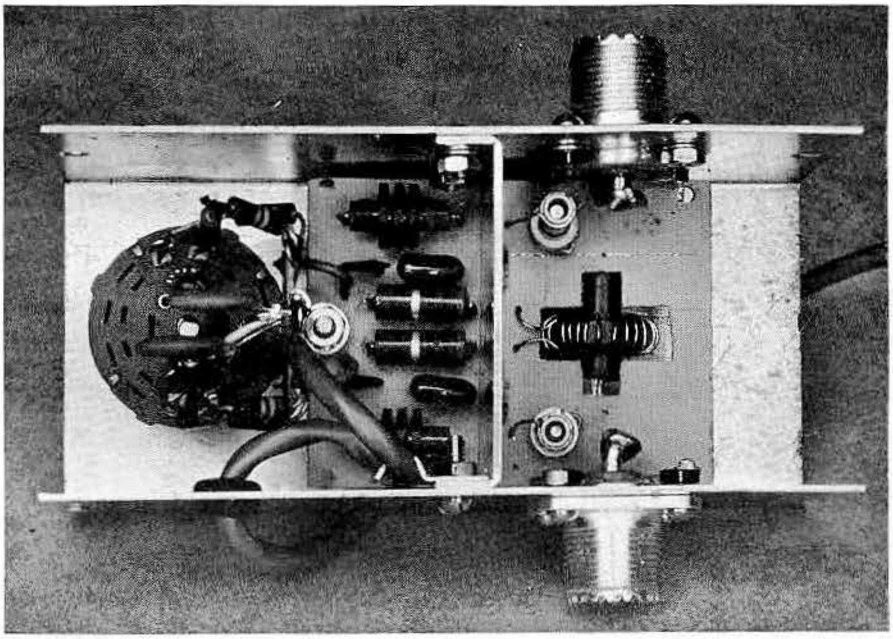
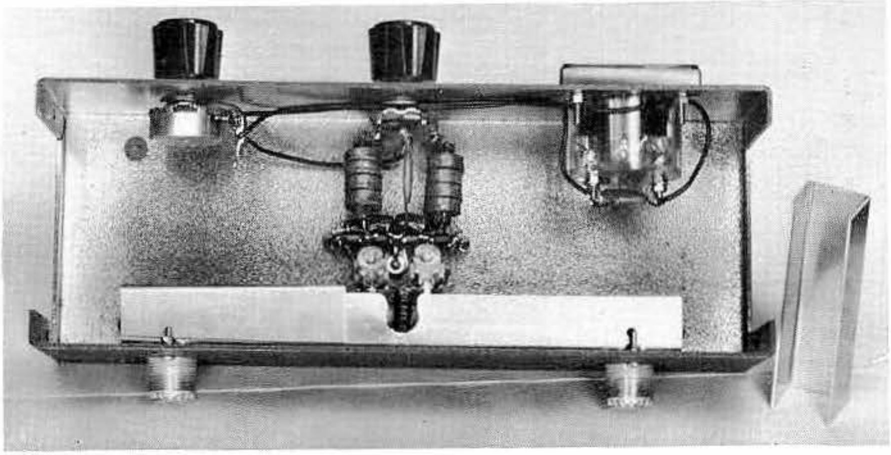


Fig. 39 — Inside view of the 5- and 50-watt power meter rf head. Component values are the same as in the circuit of Fig. 38, except for the calibrating resistances (see text). An aluminum shield isolates the through-line and toroid from the remainder of the circuit. A 50-μA meter is used in this model.

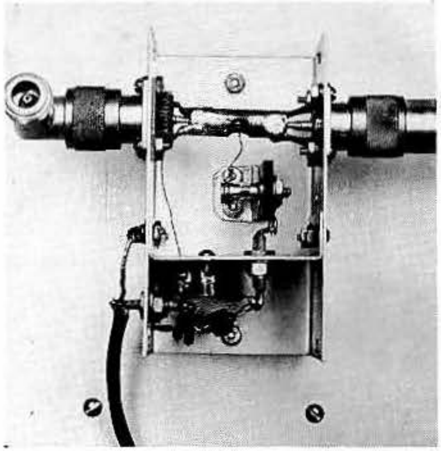
should be connected between J2 and the dummy load during the tests, providing power calibation points against which to plot the scale of M1. Apply transmitter output power to J1, gradually, until M1 begins to deflect upward. Increase transmitter power and adjust R4 so that a full-scale meter reading occurs when 100 watts is indicated on the rf ammeter or other standard in use. Next, switch S2 to REFLECTED and turn the transmitter off. Temporarily short across R3, turn the transmitter on, and gradually increase power until a meter reading is noted. With an insulated screwdriver adjust C2 for a null in the meter reading.

The next step is to reverse the coax connections to J1 and J2. Place S2 in the REFLECTED position and apply transmitter power until the meter reads full scale at 100 watts output. In this mode the REFLECTED position actually reads forward power because the bridge is reversed. Calibrating resistance R3 is set to obtain 100 watts full scale during this adjustment. Now, switch S2 to FORWARD and temporarily place a short across R4. Adjust C1 for a null reading on M1. Repeat the foregoing steps until no further improvement can be obtained. It will not be necessary to repeat the nulling adjustments on the 1000-watt range, but R5 and R6 will have to be adjusted to provide a full-scale meter reading at 1000 watts. If insufficient meter deflection is available for nulling adjustments on the 100-watt range, it may be necessary to adjust C1 and C2 at some power level higher than 100 watts. If the capacitors tune through a null, but the meter will not drop all the way to zero, chances are that some rf is leaking into the bridge circuit through stray coupling. If so, it may be necessary to experiment with the shielding of the through-line section of the rf head. If only a small residual reading is noted it will be of minor importance and can be ignored. In the circuit of Fig. 38 there remained approximately one-half a meter division when the null was reached, and this occurred only on the 1000-watt range. Since this was representative of less than 2 watts of power, it was deemed inconsequential.

With the component values given in Fig. 38 the meter readings track for both power ranges. That is, the 10-watt level on the



Inside view of the modified Heath HM-15 bridge. The new components are grouped at the center of the chassis on a 5-lug terminal strip. The nulling capacitors are connected between the inner line and the terminal strip. Press-fit aluminum shield covers are slipped over the trough line to aid in rf isolation. One cover is in place; the other is at the right of the photo. Improved shielding might be effected by installing an aluminum plate between the terminal strip and the two nulling capacitors.



Inside view of a 2000-watt power meter built by N1RM. This bridge is patterned after the circuit of Fig. 37B. Point-to-point wiring is used throughout, thus avoiding the need for a circuit board. Two piston trimmers are used for the nulling capacitors and are mounted one above the other on a phenolic block. The two 500-pF feedthrough capacitors are part of the capacitive voltage dividers.

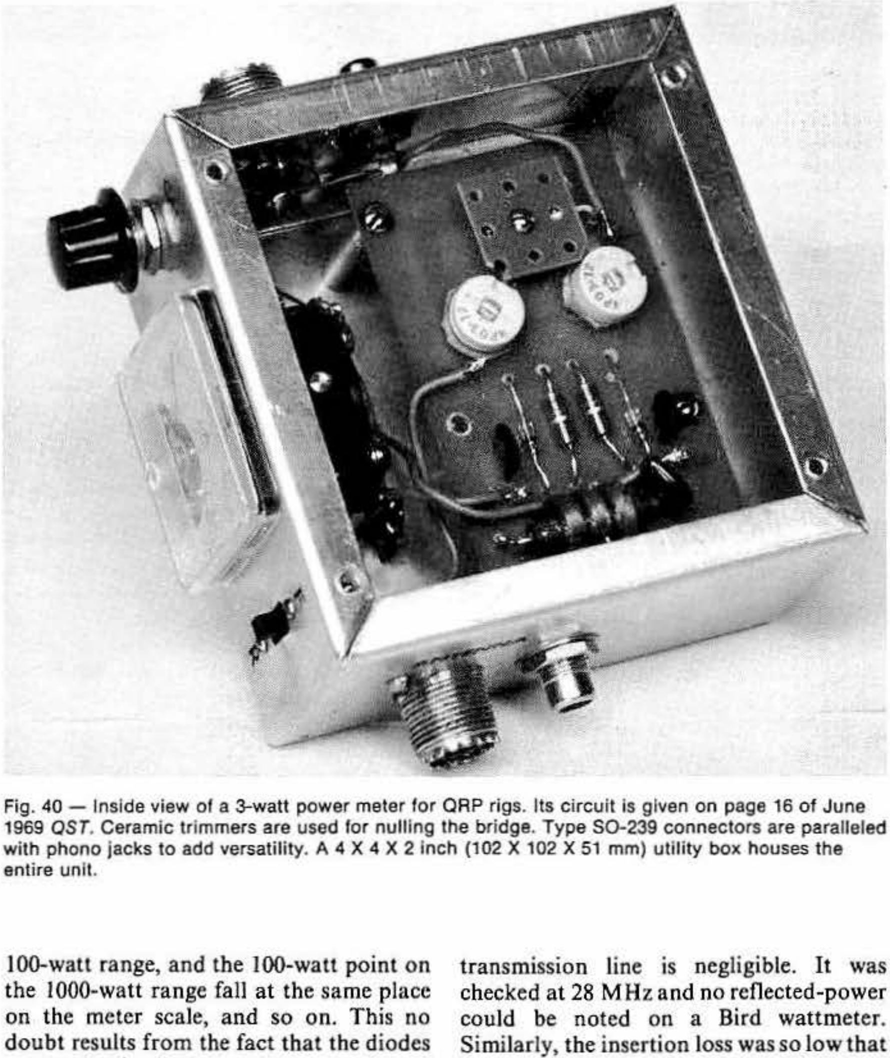


Fig. 40 — Inside view of a 3-watt power meter for QRP rigs. Its circuit is given on page 16 of June 1969 *QST*. Ceramic trimmers are used for nulling the bridge. Type SO-239 connectors are paralleled with phono jacks to add versatility. A 4 X 4 X 2 inch (102 X 102 X 51 mm) utility box houses the entire unit.

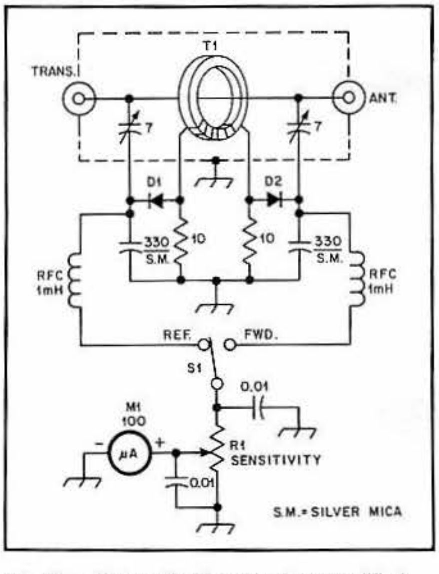


Fig. 41 — Schematic diagram of the modified Heath HM-15 SWR meter. D1, D2, M1, R1 and S1 are original components from the HM-15. T1 is the same as in Fig. 38. See text for additional details.

100-watt range, and the 100-watt point on the 1000-watt range fall at the same place on the meter scale, and so on. This no doubt results from the fact that the diodes are conducting in the most linear portion of their curve. Ordinarily, this desirable condition does not exist, making it necessary to plot separate scales for the different power ranges.

Tests indicate that the SWR caused by insertion of the power meter in the transmission line is negligible. It was checked at 28 MHz and no reflected-power could be noted on a Bird wattmeter. Similarly, the insertion loss was so low that it could not be measured with ordinary instruments.

Other Circuits

Additional circuits and photos are shown for variations in the basic design used at Fig. 38. A low-power model, having scales for 5 and 50 watts, is shown in Fig. 39. It uses fixed-value resistors for meter calibration. The required values of resistance were first determined by temporarily inserting a potentiometer in the meter line, obtaining the required full-scale reading, then substituting fixed-value resistances of the proper ohmage. The meter readings for the two power ranges do not track in this model.

A low-power meter was designed for use with the QRP transmitter described in June 1969 *QST*. It is shown in Fig. 40, and has a full-scale calibration of 3 watts. To obtain additional sensitivity, the primary of the toroidal transformer consists of a one-turn link instead of the single wire that would normally pass through the hole in the toroid core.

Some experiments were conducted to see if a Heath HM-15 SWR bridge (a Monimatch type) could be modified to work in a Bruene circuit. The results were satisfactory, and the circuit is given in Fig. 41. No attempt was made to obtain a calibration scale for the meter. The unit is being used as a simple SWR indicator, but now has better sensitivity in the lower part of the hf spectrum — 7 watts, full scale, from 3.5 to 30 MHz. Also, the instrument is no longer "frequency-conscious" as was the case before modification. The original pickup lines were discarded, the FWD-REV panel switch was rotated 180 degrees so that the labels were correct for the new circuit, and press-fit shield covers were installed on the trough line as shown in the photo. A power scale could be plotted by setting the sensitivity control in a fixed position — possibly replacing the existing control with a screwdriver-adjust type. A new 100-μA meter could be installed to provide a better scale for calibration in watts.

It was necessary to dismantle the trough line so that the toroidal transformer could be slipped over the inner line. A few wraps of mylar tape were wound over the center of the inner line to insulate the toroid winding from the line, and to provide a snug fit to keep the toroid in place. The trough was notched out with a nibbling tool to allow clearance for the toroidal transformer. Additional shielding can be added between the line and the rest of the circuit to further assure a zero meter reading in the reflected position.

It is hoped that the experimenter will find sufficient information here to enable him to build a power meter that will satisfy his specific needs. This material was originally presented in *QST* by Doug DeMaw, W1FB.

References

[1] "Monimatch Mark II," *QST*, February 1957.
[2] Bruene, "An Inside Picture of Directional Wattmeters," *QST*, April 1959.
[3] The etched-circuit board pattern and parts layout sheet for this power meter are available from ARRL hq. Send 25 cents and an s.a.s.e. Check with Circuit Board Specialists, P. O. Box 969, Pueblo, CO 81001 for negative and circuit boards.

A Resistive Antenna Bridge — Simplified

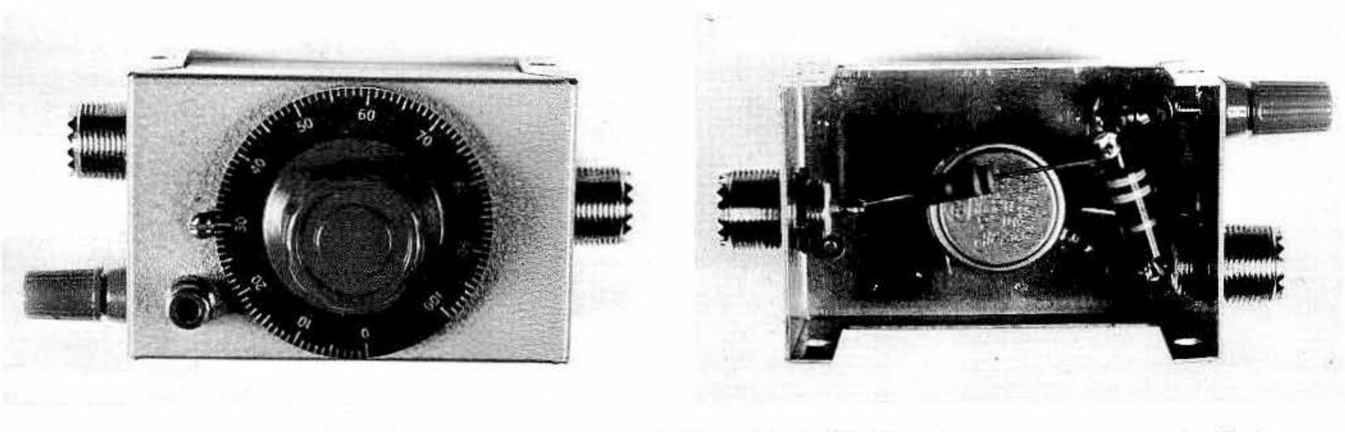
SWR indicators are neat, but when it comes to making measurements of resonant impedances, you need a true bridge type of instrument. Measure those low antenna resistances directly with this W2FMI circuit, and do it up to 30 MHz with ease!

As shown previously,[1] a bridge using a single variable capacitor can be used to measure resonant impedances of antennas and losses in coils with reasonable accuracy. With addition of an L/C network, the bridge can also be very useful in adjusting antennas for resonance conditions. Recently it was brought to the author's attention that a bridge using a variable resistance could also perform well. This is possible because the range of antenna impedances is generally low enough to allow for low values of resistance in the arms of the bridge. Under these conditions parasitic capacitances are negligible up to 30 MHz.

Resistive bridges have the advantages of small size, readily available components, and dial calibrations which can be made practically linear. Two bridges are shown with their respective calibration curves. The first is a linear device. The second expands the lower portion of the calibration curve, 0 to 30 ohms, to measure lower values of antenna impedance and coil losses more accurately.

Bridge Details

The resistive bridge with a variable resistance in one arm and equal resistances in the other two is shown in the photographs, and schematically in Fig. 42A. The nonlinear bridge is similar mechanically. The small enclosures and compact layout minimize lead lengths. With the linear version the dial practically reads directly in



Exterior and interior view of the resistive bridge. Appearance and component arrangement are essentially the same for the two types described.

[1] Sevick, "Simple RF Bridges," April 1975 *QST*, page 11.

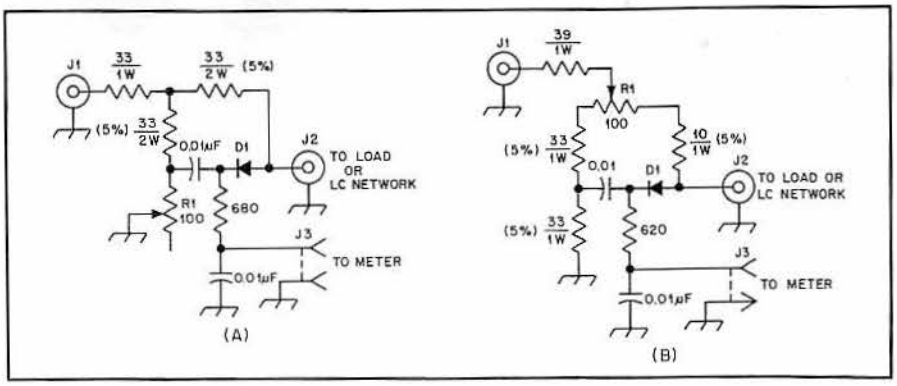


Fig. 42 — Schematic diagram and parts information for the linear (A) and nonlinear (B) resistance bridges. Resistor wattages are the minimum recommended.
D1 — Germanium diode.
J1, J2 — Coaxial connector, chassis type.
J3 — Phono jack.
R1 — 100-ohm, 2-watt linear control (Allen-Bradley, Type J).

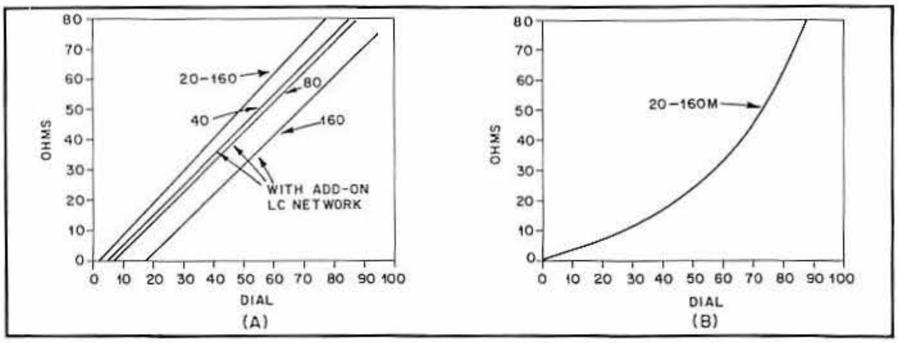


Fig. 43 — Calibration curves for the linear (A) and nonlinear (B) resistance bridges. The add-on L/C network used was described in the author's *QST* article on capacitive bridges.

ohms. In using the L/C network described in the previous article, a constant offset occurs, because of ohmic loss in the coils. This can be as high as 20 ohms, as is shown by the 160-meter curve with the L/C network, Fig. 43A.

The variable resistor used in the bridges has a parasitic (stray) capacitance of the order of 10 to 20 pF, which has little effect even at 14 MHz. Other potentiometers of similar design can probably be substituted. The calibration curves provide a good check. If the difference between the calibrations for the lowest and highest frequencies to be used is greater than an ohm or two, parasitic capacitances are probably excessive.

The nonlinear bridge uses most of the same components, but the control is connected in the differential mode, as shown in Fig. 42B. Resistance is subtracted from one arm and added to the other, tending to spread out the low end of the resistance scale for increased accuracy. In this version, the dial can be read easily to 0.5 ohm.

Results

The author has found these resistance bridges to be entirely satisfactory for measurements in the range of 1.8 to 30 MHz. Because of their greatly expanded scales, as compared with the capacitive bridges, and generally lower values of resistance in all arms of the bridge, they tend to have less marked nulls when used with very low-power signal sources. Increasing the minimum power to 20 or 30 milliwatts, when using the sensitive meter described previously, should take care of this.

In closing, the writer wishes to thank Roger A. Sykes, W1PP, for bringing the resistive bridge to the author's attention. This material was originally presented in *QST* by Jerry Sevick, W2FMI.

Why a Transmatch?

Let's cut away some of the mumbo jumbo about antennas. Here's some basic information to help the newcomer make the decision that best suits his need.

These days, nearly all transmitters have a pi-network tank circuit in the final amplifier. There are good reasons for this. With the pi tank it is possible to design a band-switching transmitter with excellent shielding (in order to prevent undesired harmonic radiation as far as TVI is concerned) and to accomplish the job with a minimum of complications. Additionally, the tank circuit easily can be set up to work into 50- or 70-ohm loads, the characteristic impedance of the popular types of coaxial feed lines. However, as we will see, this is where a "clinker" can get into the act.

When a pi network is designed to work into a 50-ohm load, the load *must* be 50 ohms in order for the transmitter to work at full efficiency. Merely connecting 50-ohm coax to the tank circuit does *not* accomplish this. For the tank to "see" a 50-ohm load, the far end of the coax — the load or antenna end — must also have the same impedance as the coax, 50 ohms. If the load is not 50 ohms the pi network will see some other value than 50 ohms. Usually, too, the tank will see reactance as well as resistance when the line is not matched. While reactance is expressed in ohms, it isn't a true resistance, and what it does is make it more difficult to put power into the line unless certain steps are taken to compensate for it.

Pi-Network Tank Circuits

In the conventional transmitter pi tank we have two controls, customarily referred to as the "tuning" and "loading" controls. The tuning control is the one that resonates the tank circuit to the desired frequency. The loading control, when adjusted properly, permits the final amplifier stage to be loaded to the desired input. To a limited extent it can also be used to compensate for the reactance in the load.

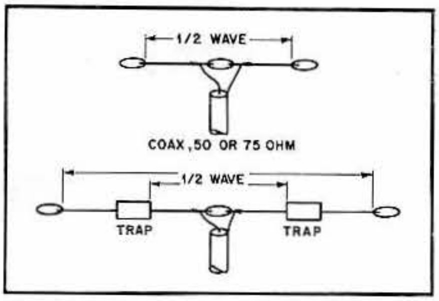


Fig. 44 — At the top is a simple half-wave dipole using coax feed. At the bottom is a drawing of a trap dipole. When a signal is fed to this antenna, for example an 80-meter one, the feed line "sees" a more-or-less resonant antenna on 80. When the transmitter is switched to 40, the traps "divorce" the 80-meter portion and the feed line sees a resonant 40-meter half-wave.

The clinker in this is that the reactance of many antenna-system loads may have too wide a range for the loading capacitor to handle. If you've ever been in the situation where is was impossible to load (or unload) the amplifier stage, the likely reason is that the load is too reactive to be handled by the tank circuit.

Such a condition can lead to some serious difficulties. While a correctly tuned pi network will offer good harmonic attenuation, an improperly adjusted tank may provide *no* harmonic attenuation. In fact, many Novices who receive second-harmonic violation notices for their 80-meter operation can lay the blame on poor loads and incorrectly adjusted tank circuits. This leads us to the real crux of the problem. How do we get a 50-ohm load on the various bands and frequencies desired?

Antenna Loads

As we said earlier, in order for a transmitter to see a 50-ohm load the far end of the 50-ohm coax must also see 50 ohms. The point where you feed the antenna has a certain impedance; in a half-wave dipole, for example, the impedance will be in the neighborhood of 50 ohms, depending somewhat on the dipole's height above ground. Also, at resonance there will be no reactance in the impedance. When we change frequency, the antenna is no longer resonant and reactance is introduced into the impedance. In turn, reactance is present at the transmitter end of the line. Whether or not the transmitter tank circuit can compensate for it will depend on the range of the loading capacitor.

How do we go about getting an antenna that will look like 50 ohms over a wide range of frequencies within a band — and, for that matter, on several bands? It isn't exactly easy.

For example, if we cut an 80-meter half-wave dipole for the center of the band, 3750 kHz, it is possible to obtain a fairly good match for 50-ohm coax at that frequency and approximately 50 kHz each side of 3750 kHz. However, at the band edges, 3500 and 4000 kHz, the impedance will be very reactive and the mismatch between the coax and the feed point may be as high as 10 to 1. It would be difficult, if not impossible, for our pi network to handle that type of mismatch. Actually, there is no "simple" antenna, by ham standards, that can be coax fed on 80 meters and cover the entire band with a reasonable match. The 40-, 20- and 15-meter bands are narrow enough so that the pi tank will handle a coax-fed dipole under normal circumstances. However, a coax-fed dipole is essentially a one-band system so such an antenna is not the answer if we want to work "all" bands and all frequencies with a single antenna.

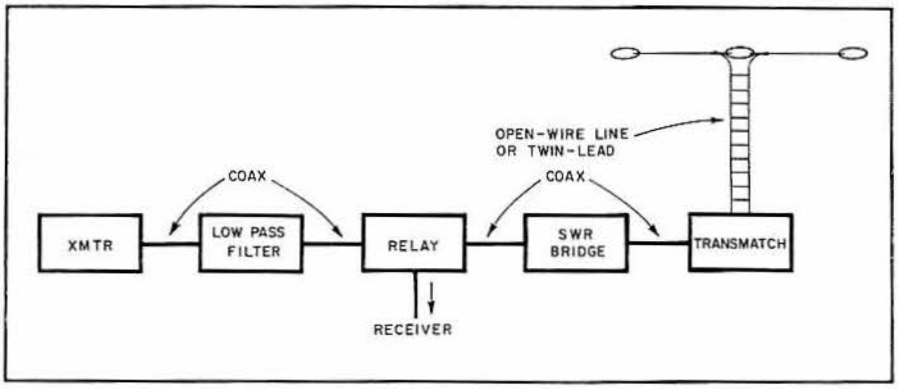


Fig. 45 — This drawing shows an ideal multiband antenna system. The units can be connected together by either 50- or 70-ohm coaxial line. The SWR bridge must match the line used. By putting the antenna relay in this section of the line, the Transmatch can be used to advantage for receiving as well as transmitting.

Trap Antennas

One type of multiband antenna with coax feed is the trap antenna, either horizontal or vertical. The horizontal variety is essentially a dipole with traps added to divorce parts of the antenna so the coax "sees" an electrically resonant dipole on the band in use. However, the trap dipole is no "broader" than a single dipole. Fig. 44 shows such a trap dipole antenna.

There are a couple of drawbacks to trap dipoles. First, a coax-fed single-band dipole is essentially a selective circuit, in that it tends to discourage undesired harmonics from being accepted and radiated. For example, a 40-meter harmonic would have a tough time in an 80-meter coax-fed dipole because the antenna and line are badly mismatched on 40. A trap system, however, does not discriminate against such undesired signals. Also, traps introduce power loss — probably not a great deal, but nevertheless loss. But if you want to use coax line and have multiband operation, the trap dipole is an answer. On the other hand, a Novice may ask, "Is there a better multiband system, one without the trap losses and harmonic problems?" The answer is yes, but before describing it let's take a look at feed lines.

Feed Lines

Three common types of feed lines are used by amateurs: coaxial, twin-lead, and open-wire. Each has a certain amount of loss, with coax the lossiest, twin-lead next, and open-wire line the most efficient. An important point to keep in mind is that the greater the mismatch, or standing-wave ratio, on the transmission line, the greater the line loss. Also, the loss in any line increases with frequency: The loss will be least at 80 meters and will become progressively greater as we approach vhf or uhf. As an example, the loss in 100 feet (30.48 m) of RG-58/U line at 144 MHz is about 6 decibels. Translating this to power, if we had a transmitter that was putting out 100 watts only about 25 watts would reach the antenna, at the end of a 100-foot (30.48 m) line, to be radiated. The remaining 75 watts would be dissipated as heat in the line! And, most important, this figure is based on the coax being *matched* at the antenna end. The mismatch or SWR will depend entirely on the impedance of the transmission line and the impedance of the antenna. If there is a mismatch, the losses increase. On 80 meters, this same coax has a loss of less than 1 dB for 100 feet (30.48 m) of line, so we could tolerate more of a mismatch.

But don't overlook the fact that if the line and antenna are mismatched it may be impossible to make the amplifier load, even if the extra loss can be tolerated. The question that then comes to mind is if we use a low-loss line so we can tolerate a high degree of mismatch, how can we make the transmitter see a 50-ohm load? The answer to this is to use a Transmatch between the transmitter and antenna.

The Transmatch

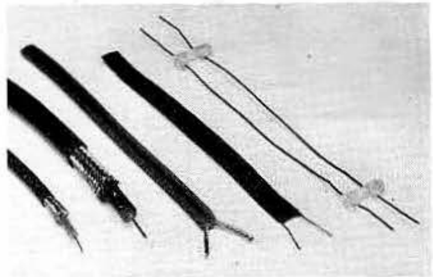
A Transmatch is simply an adjustable rf transformer that converts an unknown load (antenna side) to a desired load (transmitter side). It consists of inductances and capacitances which can be adjusted to provide a perfect 50-ohm load for the transmitter on any band or frequency.

Let's take an example to show how a Transmatch can do the job. The impedance at the center of an 80-meter dipole is

Approximate Attenuation in Decibels/100 ft. (30.48 m)

Type	Z_0	3.5	7.0	14.0	21.0	28.0	50.	144	220	420
RG-58/U	52.5	0.68	1.0	1.5	1.9	2.2	3.1	5.7	7.2	10.4
100W. Output		8	18	28	35	38	51	72	81	92
RG-8/U	52.	0.30	0.45	0.66	0.83	0.98	1.35	2.5	3.3	4.8
RG-59/U	73	0.64	0.90	1.3	1.6	1.8	2.4	4.2	5.2	7.2
RG-11/U	75	0.38	0.55	0.80	0.98	1.15	1.55	2.8	3.8	4.9
Twin-lead	300	0.18	0.28	0.41	0.52	0.60	0.85	1.55	1.9	2.8
Open-wire	—	0.03	0.05	0.07	0.08	0.1	0.13	0.25		

This chart shows the attenuation figures in decibels for common types of feed lines. Z_0 is the nominal impedance. In the case of open-wire line, the impedance will depend on the size of the conductors and their spacing. The second line of the chart indicates the amount of power that would be lost in a 100-foot (30.48 m) run of RG-58/U when properly matched. For example, on 21 MHz, the loss per 100 feet (30.48 m) is 1.9 dB. With 100 watts output from the transmitter, 1.9 dB represents a loss of 35 watts in the line. A mismatch will increase the line loss.



At the left are two examples of coaxial feed lines. The three lines at the right are balanced-type lines, 70-ohm, 300-ohm twin-lead, and TV open-wire line.

between 50 and 70 ohms on 80 meters. On 40 meters, the impedance at the same point on this same antenna is about 4000 ohms. If we feed this antenna with 300-ohm twin-lead the mismatch on 40 would be on the order of 13 or 14 to 1. However, bear in mind that 300-ohm line has relatively low loss, so we can probably tolerate the high SWR if the line is fairly short — less than 100 feet (30.48 m). Our only problem in making this antenna work on 40 is to take care of coupling the line to the transmitter. To do this the feed line is connected to the Transmatch and the Transmatch is then adjusted so that the transmitter sees a 50-ohm load. What we have now is an 80-meter dipole being used efficiently on 40, and our transmitter is working into the load it was designed for.

Now let's suppose that we feed this same antenna with 50-ohm coax. On 40, the mismatch would be 4000/50, or about 80 to 1! Because coax is not a low-loss line, the loss in the transmission line would be prohibitive. However, with twin-lead — or, even better, open-wire line — the loss is usually insignificant.

Also, and most important, a Transmatch adds selectivity at the output of the transmitter. It will discriminate against any undesired harmonics or spurious signals. And, if the antenna switching is set up so that the Transmatch is in the circuit on receiving, it will provide more selectivity for the receiver. In fact, a common problem for hams who live near broadcast stations is cross-modulation of 80- and 40-meter ham signals by the strong bc signal. A Transmatch will provide enough selectivity in most cases to eliminate bc cross modulation when it occurs in the receiver's front end.

Many hams are reluctant to use a Transmatch because it requires additional adjustments. However, the advantages are so great in a multiband system that any additional adjustments are more than worth the effort. With a Transmatch, the antenna doesn't have to be a half wave long to work on any band. For example, we described a complete multiband system just recently[1] using an antenna only 100 feet (30.48 m) long. Most hams can manage to get up a 60-foot (18.29-m) dipole, either horizontal or in an inverted-V configuration, and such an antenna also will work on 80 through 10. One method of putting up a multiband system is to find two supports for each end of the antenna, cut a wire long enough to run between them, put an insulator in the center of the antenna and at each end, and attach open-wire or twin-lead feeders long enough to reach the station. That's all there is to it. Bear in mind that a dipole fed this way doesn't have to be a half wave long; it can be any length, and it will work. Of course it is always a good idea to make it as long as possible and get it up as high as possible. Also, if possible, make it at least 1/4-wavelength long at its lowest operating frequency — about 60 feet (18.29 m) for 80 meters, for example.

A Few Notes

Many hams are reluctant to use open-wire line because of the problems in getting it into the shack from outdoors. One simple answer to this is to bring the line to the entrance — window sill, doorway, or whatever — and at that point attach 300-ohm twin-lead (which is insulated) and run the twin-lead in to the Transmatch. The fact that the two lines are not alike is of no concern because the load at the antenna side of the Transmatch is going to be some unknown value anyhow.

You may have read or heard that you must use coaxial lines in order to avoid TVI. Don't believe it. If you have a well-shielded transmitter and use a low-pass filter with it you won't have any harmonics coming out. Ask youself this simple question: "If there are harmonics, what difference can the kind of transmission line make?" The answer is, of course, "No difference."

One of the beauties in using a Transmatch is that the coaxial line between it and the rig can always be matched, and this matched section is where you put your low-pass filter. This eliminates any danger to the filter from excessive voltage or current caused by a mismatch.

One typical Novice question is "If my transmitter loads properly and I have no TVI problem, do I need more matching between the transmitter and antenna? I am using coax feed. What good would it do me to pay for the additional complexity of changing from band to band?" The answer to such a question depends on several factors. Is the harmonic attenuation — not TVI, but low-frequency harmonics — adequate? This could be a problem the Novice isn't aware of. As to the complexities of band changing, this will depend on how much the Novice desires to work other bands.

What we have tried to do in this article is to show the reader the problems and the recommended cure. There is nothing new about the multiband system using tuned feeders; it has been used for many years, and the interesting thing about it is that it is still the best multiband system. For further information it is recommended that the newcomer study *Understanding Amateur Radio* and *The ARRL Antenna Book* to gain a better insight as to how antennas work. This material was originally presented in *QST* by Lewis G. McCoy, W1ICP.

References

[1] McCoy, "A Complete Multiband Antenna System," *QST*, November 1967.

The Ultimate Transmatch

Most hams would like to own a Transmatch that could cover 80 through 10 meters, and work during coax-to-coax or balanced-lines conditions. Here is just such a unit. It will match the proverbial bedsprings, or any other nonresonant or resonant antenna — without plug-in coils or band switching — even on 160 meters.

Some amateurs assume that because they use coaxial feed lines they don't need a Transmatch. This can be an incorrect assumption.

The Harmonic Problem

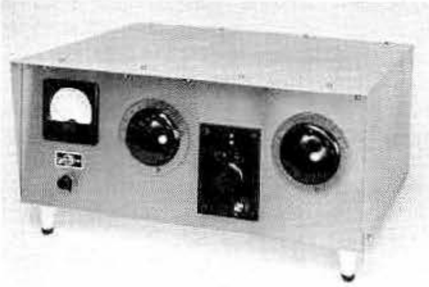
A large number of hams have found to their sorrow that the harmonic suppression in their transmitters may leave much to be desired. The FCC issues many citations to Novices each year for second-harmonic violations.

A typical Novice station might consist of a transmitter and receiver, with direct coax feed to a trap dipole or vertical antenna. In a properly adjusted transmitter of typical design, often there is insufficient attenuation of the second-harmonic energy. This can mean that the second harmonic of the signal can reach the antenna and be radiated. What is required to eliminate or reduce the second harmonic, and higher-order harmonics, is more selectivity between the transmitter and the antenna. A Transmatch is an excellent aid in taking care of the harmonic problem.

The 50-Ohm-Load Problem

Still another reason for using a Transmatch is that nearly all manufacturers of transmitters design their rigs to work into a nonreactive, 50-ohm load. Any departure from this load impedance causes difficulty in tuning and loading the final-amplifier stage. It might be pertinent to point out that simply because a ham uses 50-ohm coax, it doesn't necessarily follow that he will have a 50-ohm load. Basically, in order to have a 50-ohm load when using 50-ohm coax, the coax must be terminated in a 50-ohm resistive impedance. In other words, the antenna impedance must be 50 ohms.

When the terminating impedance of the coaxial cable is other than 50 ohms, then the transmitter will be "looking" at some value other than 50 ohms. It is practically impossible to design a single antenna that will have an impedance of 50 ohms on all of the bands a ham might want to use. One answer to the problem is to employ a device that will "match" the unknown load to the 50-ohm impedance required by the transmitter. One such circuit or device is a Transmatch, simply an adjustable rf transformer that can match the unknown load presented by the transmitter end of the feed line to the required 50-ohm transmitter impedance.



The kW version of the Ultimate Transmatch. The knobs and dial counter are standard Millen components. The front bottom of the cabinet is tilted by means of two 2-inch (51 mm) standoff insulators used as feet.

Receiver Cross-Modulation

In addition to taking care of the problems just outlined, a Transmatch can serve another very useful function at the receiver. Some receivers are susceptible to what is known as cross-modulation, or front-end overloading, by strong nearby radio stations. This is particularly true on 160 or 80 meters when a broadcast station is nearby. The bc station overloads the front end of the communications receiver, causing "birdies" and other unwanted responses across the band. A Transmatch will eliminate or greatly reduce this problem in nearly all instances.

The Ultimate Transmatch

We shall describe two Transmatches — one for the Novice power limit, and another for the legal 2-kW PEP limit. We have found that many amateurs on the verge of taking their General, or higher-class licenses, would rather invest initially in a unit that will take care of all of their future needs.

Some years ago, a Transmatch was described that was designed for use with coaxial feed lines.[1] It was called "the 50-Ohm Transmatch." This unit handles mismatches on the order of 4:1. It can transform a load of about 200 ohms, or 12 ohms, to a 50-ohm impedance. The circuit of the Transmatch described in this article, Fig. 46, is similar, but with two notable exceptions. In place of a tapped, switched inductor, a variable inductor is used. (The idea for this innovation came from Al LaPlaca, K2DDK.) The variable inductor is a coil wound on an insulated form that can be rotated so that a movable wheel shorts out and grounds the unused portion of the coil. Using the roller inductor, along with the two variable capacitors, the Transmatch provides an almost unlimited matching range, plus the feature of 80- through 10-meter coverage without band switching. With the values shown in the units, it is even possible to add one fixed capacitor to obtain 160-meter coverage.

The other exception is the use of a 1:4 (unbalanced-to-balanced) balun transformer on the output side of the Transmatch, which permits the use of balanced feed lines. This means that a Transmatch can cover 160 through 10 meters (including the MARS frequencies). It can be used to match into coaxial lines, random-length end-fed wires, or balanced feeders, and can do the job without using switches.

The two units shown in the photographs underwent extensive tests as to efficiency, power-handling capabilities, and methods of adjustment. In coax-to-coax tests, power inputs and outputs through the Transmatch were carefully measured while using Bird Thruline wattmeters and an adjustable dummy load. As carefully as could be measured, and with indicated mismatches of up to 15:1, the Transmatches showed an efficiency of over 95 percent. This small loss in efficiency more than outweighs the usefulness of the device.

Many tests were made with the high-power version to check heating of the roller inductor and the balun. Under a key-down condition, with 1200 watts indicated power through the Transmatch, the transmitter was kept on for 15-minute periods. In one test, the measured rf current through the coil was in excess of 15 amperes. The roller inductor used in the unit is rated at 5 amperes, so this was considered a fairly rugged test. The coil did get warm, but not enough to be a cause for concern. Keep in mind that in regular amateur work, 15

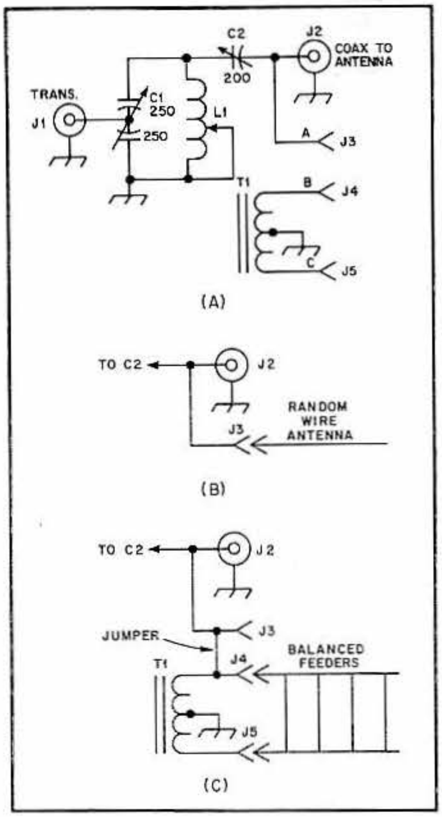


Fig. 46 — Circuit diagram of the Ultimate Transmatch.
C1 — Split-stator variable, 250 pF per section; see text. For low-power version, E. F. Johnson type 16250; or similar, for high-power version, Millen type 16250, or similar.
C2 — 200-pF variable, for low power, E. F. Johnson type 167-12 or similar, for high power, Millen type 16520 0.171-inch (0.43 cm) spacing, 16520A, 0.077-inch (2 mm) spacing, or similar.
J1, J2 — Coax chassis fitting, type SO-239.
J3, J4, J5 — Feed through insulators.
L1 — Roller inductor, see text. If 160-meter operation is desired, total inductance should be 28 μH, E. F. Johnson type 229-203; otherwise, 18 μH is adequate, E. F. Johnson type 229-202.
T1 — 1-to-4 balun; see text for details, cores are Amidon type T-200-2.

minutes would be a ridiculous figure for continuous operation.[2] In cw and ssb operation, the duty cycle would be in terms of seconds or even fractions of seconds.

The balun used for balanced operation in the high-power unit was made up from three Amidon 1-kW cores — more about that in a moment. N1RM has made extensive checks on a single-core balun. It was found that a single core would easily handle 500 watts of power during severe mismatch conditions. Failure of the core, most likely due to saturation and heating, took place at the 700-watt level. In the high-power Transmatch shown here, three cores are used. They are wrapped with glass insulating tape and then wound with Teflon covered wire. Wire insulation material can be important because of the extremely high rf voltages that may be developed with some load conditions. In many tests of long duration, using up to 1400 watts output into a dummy load, it was almost impossible to detect any heating of the balun.

Bear in mind that the balun would only be needed if balanced-line operation were desired. For coax-to-coax or random-wire feed, the balun can be omitted.

Construction Information

A look at Fig. 46, at A, will show that the circuit is a very simple one. The input line from the transmitter is connected to the rotor of C1, a split-stator capacitor. This means that the capacitor must be insulated from the chassis, using standoff pillars, and from the panel by means of an insulated shaft coupler. The same is true for C2. In the kW unit shown, we have installed a power bridge. Construction details are not given here for the bridge because such a unit was described in detail in *QST*[3]. Also, many amateurs already have a Monimatch[4] or some other type of SWR indicator. An SWR bridge or matching indicator is needed in the 50-ohm line between the rig and the Transmatch to show when the Transmatch is correctly adjusted.

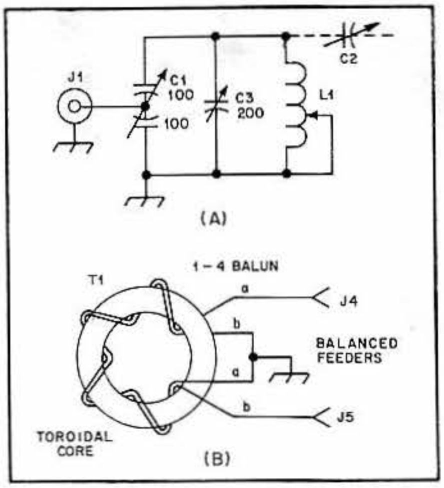
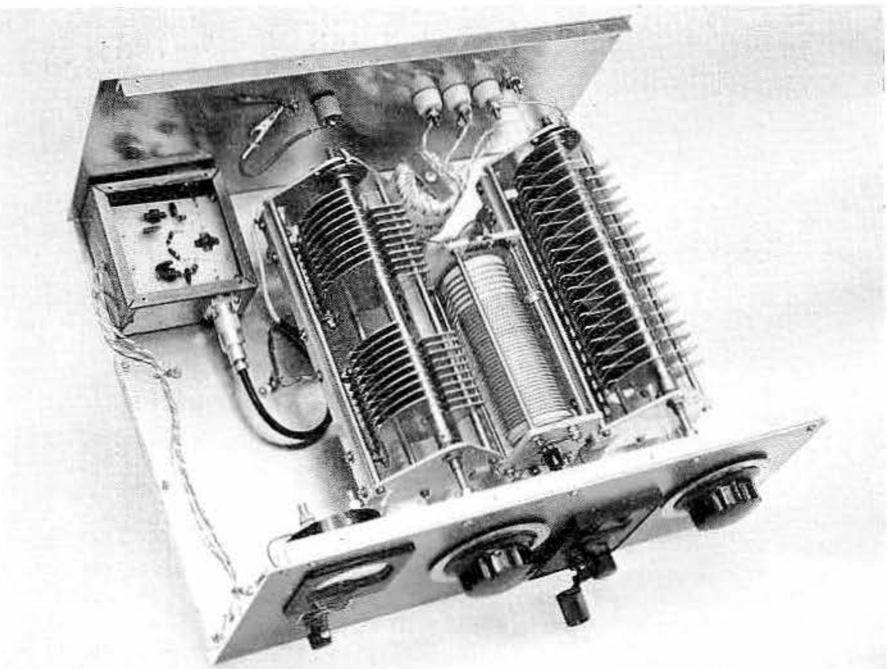


Fig. 47 — At A, details for padding a low-value variable for C1 by installing a second variable, C3, the same value as the low-power unit C2. In the case of tuning 160 meters, using an inductor of 28 μH for L1, and 250 pF per section for C1, a fixed capacitor of 100 pF can be used at C3, Centralab type 850-100N, or similar. At B, details for connecting the bifilar windings on the balun are given. The ungrounded leads a and b are connected to J3 and J4, the feedthrough insulator terminals.

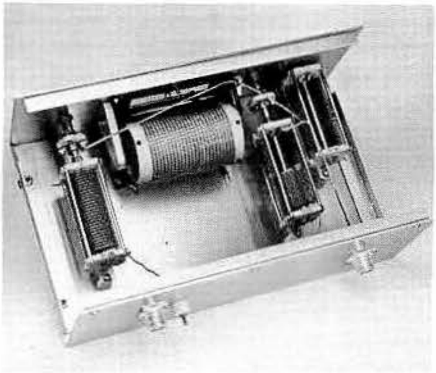
Layout of the components should follow the same arrangement shown in the photographs — C1 at the input side, the roller inductor at the center, and then C2. If a balun is going to be installed, allow enough room behind the roller coil for mounting the balun. In the two units shown, the cabinets are made up from aluminum sheet stock. If desired, a commercial chassis and cabinet can be used. In the low-power Transmatch, leave at least 1/2-inch (13 mm) spacing between the edges of the capacitors and any part of the chassis and cabinet. Allow 1-inch (25 mm) spacing in the kW unit.

Balun Details

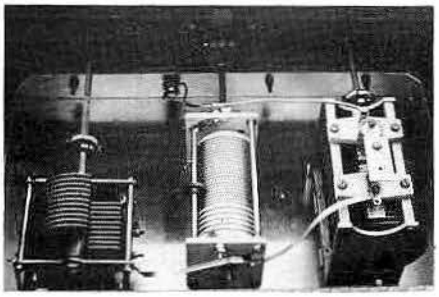
For the low-power Transmatch, a single toroid core will more than handle the power. Incidentally, the low-power unit was tested under all conditions at about 100 watts through the Transmatch. The



At the rear of the roller inductor is the 1:4 balun. The balun is set on top of a standoff insulator and is held in place with a piece of insulated board and a screw. The fixed capacitor mounted on the rear wall is the 160-meter unit. Both the variable capacitors and inductor are mounted on 1-inch (25 mm) high standoff insulators.



This is the low-power Transmatch. The salvaged roller inductor is mounted on the front panel, making use of the original mounting brackets.



Here is an inside view of the Ultimate Transmatch as built by Al LaPlaca, K2DDK, who came up the idea of using the roller inductor. The installation on top the right-hand capacitor is the homemade 160-meter switch and fixed loading capacitor.

power-handling capabilities of the units depend primarily on the plate spacing used for C1 and C2, aside from the balun requirements mentioned earlier. At the 100-watt level, a plate spacing of 0.03 inch (0.8 mm) is adequate. A 0.045-inch (1 mm) spacing should handle 500 watts. In the kW unit shown, C1 has a 0.077-inch (2 mm) spacing. While a 0.077-inch spacing capacitor wasn't tried at C2, such plate spacing should work at the kW level.

In making the low-power balun, wind two layers of Scotch brand electrical tape around the core before putting on the wire. This will provide extra insulation, and will protect the edges of the wire to prevent the enamel from being scraped away. Fig. 47, at B, shows a sketch of the winding. The winding consists of 10 bifilar turns of no. 14 Formvar insulated wire. Connected as shown, this will provide a 1:4, unbalanced-to-balanced configuration.

Three cores are needed in the high-power balun. Each core is covered with two layers of 3-M type 27 glass-cloth insulating tape. Next, the three cores are stacked, then covered with two more layers of the tape. The winding consists of 15 bifilar turns of either no. 12 or 14 insulated wire. The insulation should have a minimum rating of 1000 volts and can be either Teflon or vinyl-nylon (or any other suitable covering with a minimum voltage rating of 1000 volts).

In making the low-power Transmatch, a roller coil from a junked 40-meter ARC-5 transmitter was salvaged and installed in the unit. Many amateurs know other hams who have old ARC-5 gear, and these units are a good source for the roller coils. However, some hams may not be able to locate used ARC-5 transmitters, so we have included some information on sources of surplus and new roller inductors. There may be surplus outlets in your area worth investigating. Look for a roller coil that has a minimum inductance of 10 μH when used with C1 having a value of 200 pF per section. Such a combination will cover a low frequency of 3500 kHz. In the unit shown, in addition to the ARC-5 roller, we used a value of 100 pF per section for C1 and padded that capacitor with another of 200 pF (single section) in order to provide the required coverage. This added capacitor is shown in Fig. 47 at A. By using this approach, it is sometimes easier to save money then when trying to locate a 200-pF-per-section variable for C1. (Incidentally, you can use a variable at C1 of more than 200 pF per section for good coverage with the roller inductance specified above.)

An even better approach to get the required capacitance for C1, because it is better to maintain the symmetry of the circuit as shown in Fig. 46 at A, would be to gang two 200-pF variables to make up your own split-stator capacitor, with the desired plate spacing. (There may be some around, but we couldn't find any manufactured split-stator with the required plate spacing and capacitance). Still another approach would be to clip fixed transmitting-type mica capacitors across each section of C1 to obtain the required capacitance for use on 160 and 80.

Finding the Parts

As most hams are finding out, it is becoming more and more difficult to buy, or find, components for construction projects. Some searching was done, and the following information is worth passing on. Barry Electronics of New York City has informed us that they will fill any order for any amateur component at the manufacturer's current amateur net price. The parts specified in Fig. 46 are currently manufactured items. Also, Fair Radio Sales in Lima, OH has some surplus roller inductors and counter dials in stock. The roller-inductor catalog number is 5950-199-6469, and the counter dial is listed as RT-45. Also, Millen components can be purchased directly from G. R. Whitehouse, Amherst, NH 03031.

Using the Transmatch

One of the first considerations in using a setup for "coax-to-coax" is exactly how much, or how high an SWR can be tolerated. As has been pointed out, this Transmatch will handle *any* mismatch on the line. Without getting into a lot of details, a few observations about coaxial lines are in order. First, the higher the SWR, the greater the losses in coaxial lines. The amount of losses depends on the line construction and the *frequency* at which the line is used — the lower the frequency, the less will be the losses. For example, RG-8/U has a loss per 100 feet (30.48 m) of line of only 0.33 -dB at 3.5 MHz with an SWR of 1 (a matched condition). At 28 MHz, this same line would have a loss of slightly less than 1 dB. However, as the SWR rises, so do the losses. With an SWR of 10:1, for example, the additional losses at 3.5 MHz would amount to about 0.6 dB, or an overall loss of about 1 dB. For the same SWR at 28 MHz, the losses would be about 2.5 dB, or a total loss of about 3.5 dB. Since a loss of 3 dB would mean half of the ouput power from the rig would be dissipated in 100 feet (30.48 m) of line, one could easily tolerate the condition at 80 meters, but the losses would be prohibitive at 28 MHz. This means that the amateur would be wise to keep the match at the antenna feed point as close to 50 ohms as possible, and thereby keep the SWR low.

With trap or multiple dipoles, the SWR should be less than 5 to 1; the Transmatch would be ideal. Keep in mind that you must provide a load for a transceiver or amplifier that is close to 50 ohms. The Transmatch will provide a means.

In a coax-to-coax system, set both C1 and C2 at maximum capacitance (plates fully meshed), then feed enough power through the Transmatch to get a full-scale forward reading on your SWR indicator. It is always important to use low power when adjusting a Transmatch. Next, switch the SWR bridge to read reflected power, then run the roller inductor slowly through its range. At some point you will notice a sharp dip in the reflected-power reading. Once this point is reached you should adjust C1 and C2, with possibly a slight adjustment of the roller coil, to get a perfect match. Power can then be increased to the desired level. You'll find that several different settings of the Transmatch may provide a perfect match. The one to shoot for is the condition that requires the most capacitance at C1 and C2 for a matched condition.

If a random-length, end-fed antenna is used, merely connect the end of the antenna to terminal J3, Fig. 46B, and go through the adjustment procedures outlined above. It is helpful to have an earth ground connection on the Transmatch. Also, if possible, use an antenna length that comes out to a quarter wavelength, or odd multiple thereof. Such an antenna will be of low impedance, and will reduce the chances of high rf voltages appearing on the Transmatch or associated equipment.

If balanced feeders are used, the feeders should be connected to terminals J4 and J5 with a short jumper connected between terminals J3 and J4. Again, the previously discussed tune-up and adjustment procedures should be followed in setting up the Transmatch.

Some Other Thoughts

Some amateurs might be concerned about the amount of voltage that can be developed in a mismatched coaxial line. In a matched condition, with 1000 watts in a 50-ohm line, the rf voltage would be about 220 volts. With a standing-wave ratio or 20:1 (!), the increase in voltage would be 4-1/2 times, or approximately 990 volts. This however, is well within the rating of the RG-8/U cable.

This Transmatch should satisfy the needs of those hams who desire a multiband unit without switches or plug-in coils. Once the settings for the controls are determined, a chart can be made up for any given istallation. Band changing is then quickly done. This material was originally presented in *QST* by Lewis G. McCoy, W1ICP.

References

[1] "The 50-Ohmer Transmatch," *QST*, July 1961.

[2] [Editor's Note: However, teletype operation would be continuous (to say nothing of those long-winded a-m operators!).]

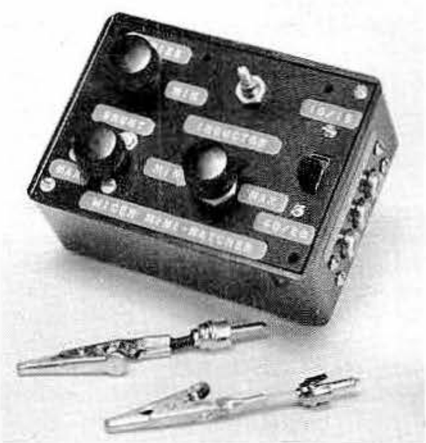
[3] "In-Line RF Power Metering," *QST*, December 1969. (See chapter 4.)

[4] *Understanding Amateur Radio*, p. 209.

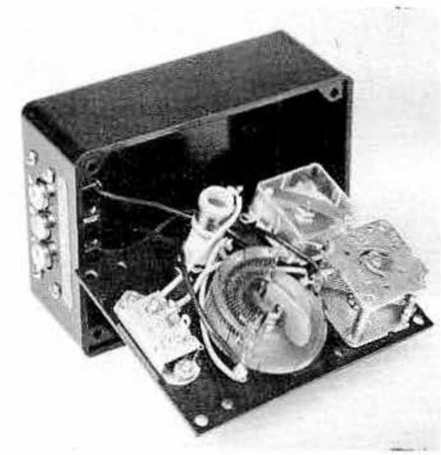
Build a Baby Ultimate

Got a match? Not a classic "match," but one between the antenna and your QRP rig may be what you need. If so, this article is for you.

Nobody needs or wants a 50-pound Transmatch during a QRP junket to a favorite lake, campsite or other distant location. The entire point of QRP operation is negated when the low-power station can be held on the palm of one's hand, but the accessory gear needs to be transported by hand truck to the car, airport or whatever! Operators who prefer to use a random-length wire antenna for field work will require a matching network between the 50-ohm transmitter output and the end of the antenna, whose characteristic impedance can be anything from a few ohms to a couple of thousand. For low-power work (25 watts or less) it doesn't take a big Transmatch to do the job, and some novel ideas can be applied to make the matcher cover 80 through 10 meters without a roller inductor or messy tapped-coil switching arrangement. This article shows some tricks that can be applied to meet that goal.



Exterior view of the Baby Ultimate. Dymo tape labels are used to identify the controls.



Interior view of the matcher showing the K1KLO variable inductor (lower center).

The heart of the Baby Transmatch is the half-toroid variable inductor. It is the by-product of a few "skull sessions" between Andy Pfieffer, K1KLO, and the writer. Both amateurs are QRP "freaks," and finding the proper mechanical technique for building a miniature panel-operated variable inductor of reasonable inductance range was challenging and productive. The machine-shop skill and impagination of K1KLO can be realized when viewing the accompanying close-up photograph. Early efforts along this line provided a slider type of full-toroid variable inductor (rheostat style), and dismal results were had: the inductor Q was very low, approximately 5, as a result of the shorted-turn syndrome. Finally, a powdered-iron Toroid core of Q1 material, 1-inch (25 mm) diameter, with 3/16 by 3/16-inch (5mm by 5mm) walls, was sawed in half and cemented to a plastic arm. The arm was glued to the shaft of the control so that it would enable the operator to change the coil inductance by moving the semicircular toroid section in and out of the coil.

The coil in this unit was air wound, then cemented to a semicircular piece of plastic which is affixed to a plastic disk of 1-1/2-inch (38 mm) diameter. The overall coil-and-plastic assembly is glued to the 3/8-inch (10 mm) bushing and 1/4-inch (6 mm) diameter control shaft. Although all of the metal work was done from scratch on a lathe, an old volume control or rheostat bushing and shaft can be modified to perform the function required. All that's needed here is some amateur ingenuity! The tuning range of the variable inductor is 3 to 9 μH, and the unloaded Q was measured as 150 at 7.9 MHz.

It is reasonable to conclude that the K1KLO "giz," as he calls it, could be made to cover a greater inductance range by making the coil bigger in ID and cementing both halves of the toroid core together — one atop the other — to provide greater permeability overall. Ferrite material is unsuitable for this component because of the hardness of ferrite. Without special cutting tools the latter will resist all efforts to saw through it. One-half of an Amidon 1-kW balun-kit, powdered-iron toroid should be excellent for larger units of this kind.

Other Circuit Features

As is shown in Fig. 48A, S1 is used to switch an additional variable inductor (L1) in parallel with the K1KLO unit, L2. This provides a lower minimum-inductance amount for operaion on 15 and 10 meters.

Fig. 48B illustrates some variations which will extend the Transmatch range down to 80 meters. The model shown photographically was designed for 40 through 10 meters. In the second example, S2 and L3 have been added to increase the total inductance to permit 80-meter matching. Also, C1 has been changed to a

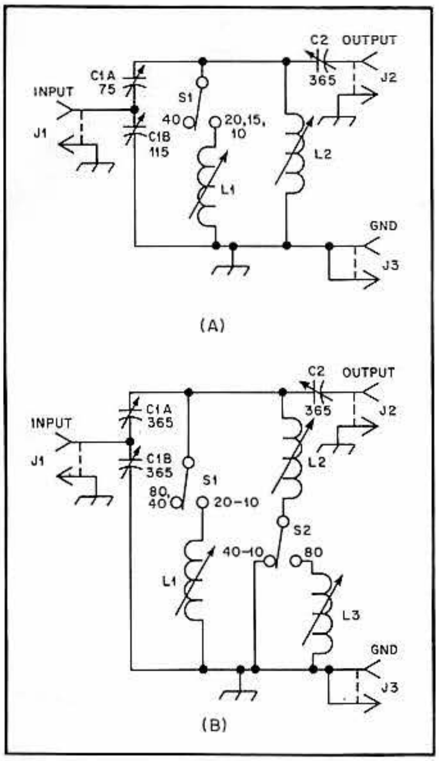


Fig. 48 — The diagram at A is for the 40- through 10-meter Transmatch. At B, a suggested circuit for coverage from 80 through 10 meters.

C1 — Dual-section air variable (Miller 2109, J. W. Miller Co., 19070 Reyes Ave., Compton, CA 90224). See text.
C2 — Calectro or Archer single-section miniature 365-pF variable.
J1-J3, incl. — Phono jack.
L1 — 3.1-to 4.8-μH slug-tuned inductor (Miller 4504 with red core).
L2 — See text. Contains 32 turns of no. 22 enam. wire, air wound, 7/16-inch (11 mm) OD.
L3 — 5.5-to 8.6-μH slug-tuned inductor (Miller 4505 with red core.)
S1, S2 — Spdt slide or toggle switch.

two-section 365-pF, bc-style variable, also for the same reason. A dual 365-pF capacitor can be used for the circuit at A, but the tuning rate will be much sharper than with the unit specified.

Three phono jacks are used for external connections. The first photograph shows a pair of clip leads which have been soldered to two phono plugs. These are used for making connections to a single-wire antenna and ground.

The slug screw of L1 protrudes from the top panel of the small plastic meter case. This feature enables the operator to have additional control of the overall inductance amount during operation on 15 or 10 meters. All internal ground connections are brought to a common point — J3, which has both of its terminals joined.

The "Ultimate" design is based on one which was popularized by W1ICP when he described in *QST* a 1-kW version of the circuit.[1] The network will match a wide range of impedances, but it should be pointed out that this circuit is not capable of providing much (if any) harmonic attenuation. Examination of the circuit will show that the network is basically a high-pass type.

Building the Transmatch

A 1-1/2 × 2-3/4 × 4-inch (38 mm × 70 mm × 102 mm) plastic meter style of case is used to house the Transmatch. The box used by the writer was made by RCA as an enclosure for a 9-volt regulated power-supply kit. Similar boxes are available at Radio Shack and other parts stores, but most have a metal cover. If the latter are used, it will be necessary for the builder to isolate the rotors of C1 and C2 from the metal plate. Adhesive-backed plastic feet are affixed to the bottom of the case. They will keep it from moving about on the operating table.

Using the Transmatch

When matching the 50-ohm transmitter to a given antenna (fed with coaxial line or single wire in nature), an SWR indicator will be necessary between the transmitter and the Transmatch.[2] C1, C2 and L2 are adjusted one at a time for the lowest reflected-power reading on the meter. There will be interaction between the controls, so it will be necessary to go over them several times to effect an SWR of 1.

Some difficulty may be encountered while working with a voltage-fed (high impedance) wire antenna. The symptom is one of hand capacitance affecting the SWR reading. In such instances the tune-and-try method will be required, moving the hands away from the box after each adjustment. For this reason the builder may wish to house the circuit in a metal box and use insulating shaft couplings on C1, C2 and L2. Of course, this will make the unit somewhat larger.

The writer used this Transmatch for two weeks in October 1975 while on a QRP sortie to Barbados (8P6EU). Maximum power used was 20 watts output, and minimum power was 2 watts ouput. The 40-, 20- and 15-meter bands were used, and all manner of antennas (end fed and coaxially fed) were employed. In all cases the SWR could be set for a 1:1 condition. Insertion loss through the Transmatch was measured at 14 MHz while delivering 20 watts to a test dummy load. The loss was approximately 0.1 dB at a matched condition. No heating of the components was noted.

One final word is in order. Always use the maximum possible amount of capacitance at C2 when adjusting the Transmatch for an SWR of 1. There can be several settings of C1, C2 and L2 which will provide a match. Best efficiency will always occur with maximum usable C at C2, and this is true of all variations of the Ultimate Transmatch.

If you're a QRP enthusiast, this matcher should be part of your setup when 50-ohm antennas aren't used. It is lightweight, small of size, and can be tucked away in the XYL's handbag when enroute, if need be! This material was originally presented in *QST* by Doug DeMaw, W1FB.

References

[1] McCoy, "The Ultimate Transmatch," *QST*, July 1970. (Included in this chapter.)

[2] DeMaw, "A QRP Man's RF Power Meter," *QST*, June 1973, p. 13.

Simple Broadband Matching Networks

This article gives complete details on constructing broadband matching transformers for ratios of 4:1, 6:1, 9:1 and 16:1.

Are you looking for a physically small DX antenna? To obtain low-angle radiation on 80 and 160 meters, many amateurs use vertical antennas. Horizontal antennas would have to be at elevations of a half-wavelength or greater to be comparable. Suitable supporting structures are beyond the reach of most amateurs at these lower-frequency bands. Quarter-wavelength verticals require some 60 feet (18.29 m) on 80 meters and 120 feet (36.58 m) on 160 meters — still very tall structures! However, short verticals over a good image plane have been shown theoretically[1] and experimentally[2] to perform practically as well as their full-size quarter-wavelength counterparts. The only problems are very low input impedances and narrower bandwidths.

This paper describes broadband matching networks which can efficiently match 50-ohm coaxial cable to verticals as short as 1/25 wavelength. Also included is information on short vertical antenna designs incorporating large top hats in order to improve bandwidth, such as a very short 40-meter vertical and a dual-band 80- and 160-meter short vertical with remote switching. In addition, loading coils using powdered-iron toroidal cores are discussed.

Connie, W2FMI's better half, is making use of the shade under Jerry's 40-meter umbrella antenna. It is hoped that Jerry warns her about touching the antenna when he is running high power!

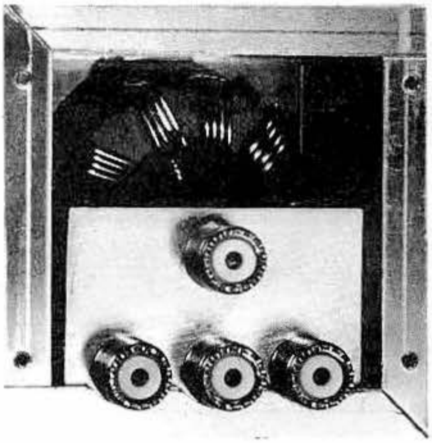
Broadband Matching Transformers

Broadband transformers have been widely used because of their inherent bandwidth ratios (as high as 20,000:1) from a few tens of kilohertz to over a thousand megahertz. This is possible because of the transmission-line nature of the windings. The interwinding capacitance is a component of the characteristic impedance and therefore, unlike the conventional transformer, forms no resonances which seriously limit the bandwidth.[3] At low frequencies, where interwinding capacitances can be neglected, these transformers are similar in operation to the conventional transformer. The main difference (and a very important one from a power standpoint) is that the windings tend to cancel out the induced flux in the core. Thus, high-permeability ferrite cores, which are not only highly nonlinear but also suffer serious damage even at flux levels as low as 200 to 500 gauss, can be used. This greatly extends the low-frequency range of performance. Since higher permeability also permits fewer turns at the lower frequencies, high-frequency performance is also improved since the upper cutoff is determined mainly from transmission-line considerations. At the high-frequency cutoff, the effect of the core is negligible.

The applications of broadband transformers to antennas and broadband circuits have been covered by a number of authors.[4,5] This paper extends the application of these transformers to include the operation of short ground-mounted vertical antennas with impedances as low as 3 to 4 ohms. Further design considerations illustrate variable matches to vertical antennas having impedances even greater than 35 ohms.

Bifilar matching transformers for ground-mounted verticals lend themselves to unbalanced operation. That is, both input and output terminals can have a common ground connection. This eliminates the third magnetizing winding required in balanced-to-unbalanced (balun) operation. By adding third and fourth windings, as well as tapping windings at appropriate points, various combinations of broadband matching can be obtained. Fig. 49 shows a 4:1 unbalanced-to-balanced configuration. This transformer can be used with verticals of 12.5 or 200 ohms when using 50-ohm cable. No. 14 wire can be used and it will easily handle 1000 watts of power. By tapping at points 1/4, 1/2 and 3/4 of the way along the top winding, ratios of approximately 1.5:1, 2:1, and 3:1 can also be obtained. It should be noted that one of the wires was covered with vinyl electrical tape in order to prevent voltage breakdown between the windings. This was necessary when a step-up ratio was used at high power to match antennas with impedances greater than 50 ohms.

Fig. 50 shows a transformer with four windings, permitting wide-band matching ratios as high as 16:1. A picture shows a four-winding transformer with taps at 4:1, 6:1, 9:1 and 16:1. In tracing the current flow in the windings when using the 16:1 tap, one sees that the top three windings carry the same current. The bottom winding, in order to maintain the proper potentials, sustains a current three times greater. The bottom current cancels out the core flux due to the other three windings. If this transformer is used to match into low impedances, like 3 to 4 ohms, the current in the bottom winding can be as high as 15 amperes if the high side of the transformer is fed with 50-ohm cable handling a kilowatt of power. If one needs a 16:1 match like this at high power, then cascading two 4:1 transformers is recommended. In this case, the transformer at the lowest impedance side only requires each winding to handle 7.5 A. Thus even no. 14 wire would suffice in this application.



A 4-winding, wideband transformer (with front cover removed) with connections made for matching ratios of 4:1, 6:1, 9:1, and 16:1. The 6:1 ratio is the top coaxial connector and, from left to right, 16:1, 9:1, and 4:1 are the others. There are 10 (quadrifilar) turns of no. 14 enameled wire on a Q1, 2.5 inch (64 mm) ferrite core.

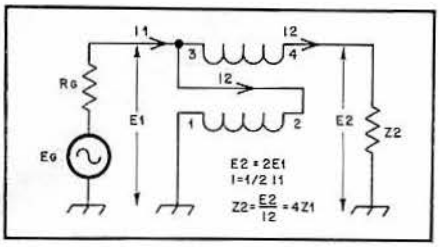


Fig. 49 — Four-to-one broadband bifilar transformer. Upper winding can be tapped at appropriate points to obtain other ratios such as 1.5:1, 2:1 and 3:1.

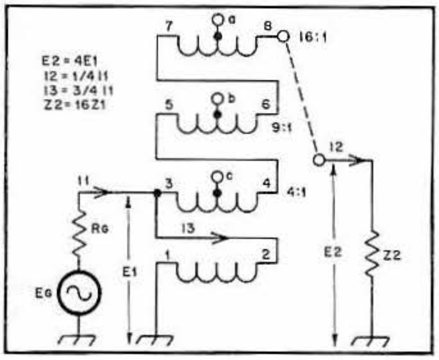


Fig. 50 — Four-winding, broadband, variable impedance transformer. Connections a, b and c can be placed at appropriate points to yield various ratios from 1.5:1 to 16:1.

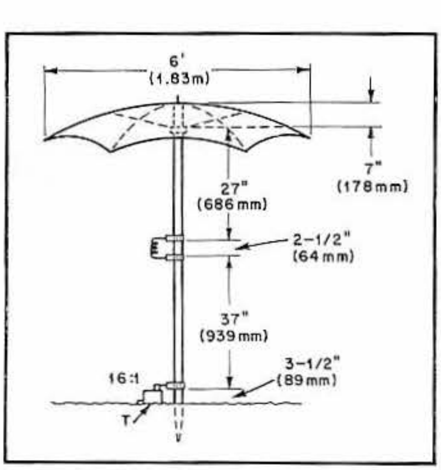


Fig. 51 — Final design and bandwidth characteristic of a short 40-meter vertical having an input impedance of 3.5 ohms and utilizing a commercial beach umbrella. This antenna established its worth as a prototype for the lower frequencies.

The popular cores used in these applications are 2.5 inch (64 mm) OD ferrites[6] of Q1 and Q2 material and powdered iron cores,[7] of 2-inch (51 mm) OD. The permeabilities of these cores, μ, are nominally 125, 40 and 10, respectively. Powdered iron cores of permeabilities 8 and 25 are also available.

In all cases these cores can be made to operate over the 10- to 160-meter bands with full power capability and very low loss. The main difference in their design is that lower permeability cores require more turns at the lower frequencies. For example, Q1 material required 10 turns to cover the 160-meter band, Q2 required 12 turns, and powdered iron ($\mu = 10$) required 14 turns. Since the more common powdered-iron core is generally smaller in diameter and requires more turns because of lower permeability, higher ratios are sometimes difficult to obtain because of physical limitations. Although most of the author's experimentation on these transformers was done on the 40-, 80- and 160-meter bands, the results indicated that they should operate on the higher bands equally well. When working with low impedance levels, unwanted parasitic inductances come into play, particularly on 14 MHz and above. In this case lead lengths should be kept to a minimum.

All the results obtained by the author have shown that the transformers can be used to match a variety of loads and impedance ratios, they can be used over many bands, and that they exhibit negligible loss in operation. More importantly, the core materials are readily available and low in cost.

A Short Vertical Antenna Design

These transformers permit efficient matching to impedances as low as 3 to 4 ohms. This means, with some top-hat loading, antennas could be 4 to 5 feet (1.22 to 1.52 m) tall on 40, 8 to 10 feet (2.44 to 3.05 m) on 80, and 16 to 20 feet (4.88 to 6.10 m) on 160 meters. With the capability of tapping off any portion of the transformer windings, thus providing variable matching, the heights of these antennas can be increased at will depending upon the bandwidth desired.

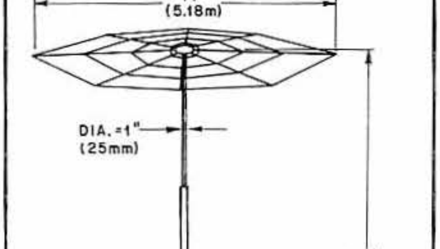


Fig. 52 — The 80- and 160-meter dual-band vertical system. The remotely switched matching network is described in the text. Not shown are three sets of polypropylene guy ropes at heights of about 9, 18 and 26 feet (2.74, 5.49 and 7.92 m).

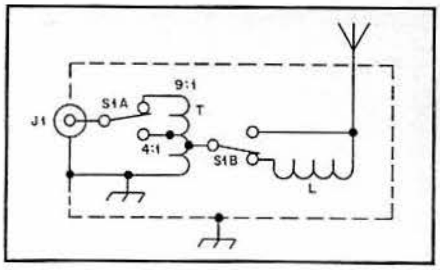


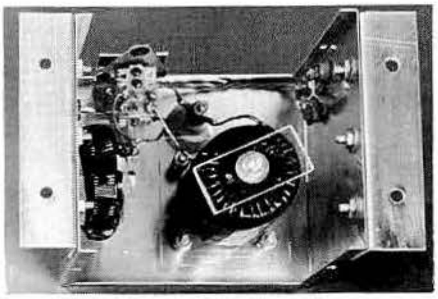
Fig. 53 — The remotely switched matching network for the 80- and 160-meter dual-band vertical antenna. The indicated switch positions are for 160-meter operation.
S1 — Dpdt antenna relay.
J1 — Coaxial connector, chassis type.
L — Load coil for 160 meters, 22-1/2 turns, no. 14 wire on 4 cores of 2-inch (51 mm) OD powdered-iron, permeability of 10 (Amidon T-200-2).
T — Broadband transformer (see text).

The first short vertical designed by the author was brought about by a trip to a local shopping center. The author saw a beach unbrella that had about the right proportions one would use in designing a short 40-meter vertical. The "antenna" was purchased (at a nominal price) and a 14-turn coil, connected across an insulated section about three feet (0.91 m) from the ground, was used to tune the vertical to resonance. The measured input impedance was 3.5 ohms and was matched easily to 50-Ω line with a 16:1 transformer. Fig. 51 shows the final design and the bandwidth characteristic. Several months of operation on 40 meters verified the outstanding capability of this short vertical antenna (with an extensive radial system) and established its worth as a prototype for the lower frequencies. A further study showed that the 6-foot (1.83 m) diameter top-section was about the equivalent of a 4-1/2-foot (1.37 m) diameter solid disk.

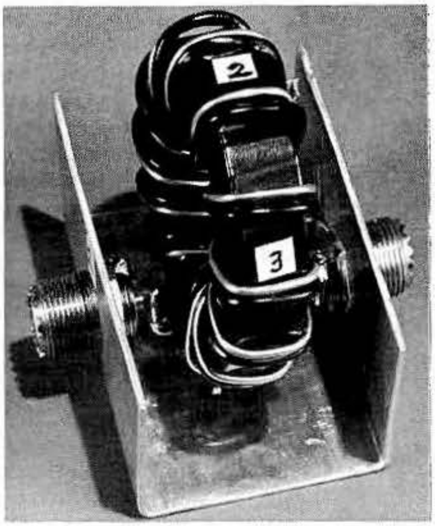
A Dual-Band 160- and 80-Meter System

The antenna shown in Fig. 52 is a dual-band design using a remotely switched matching network (see photograph) which not only changed a tap on a broadband transformer from 4:1 to 9:1, but also introduced a powdered-iron base-loading coil for 160-meter operation.

The circuit diagram for the remote matching network is shown in Fig. 53. The loading coil was made with four powdered-iron ($\mu = 10$, 2-inch [51 mm] OD) cores. They were first wrapped individually with several layers of vinyl electrical tape before being combined and wrapped again. The necessary inductance was obtained with 22-1/2 turns. A slight adjustment of the loading coil and the height of the antenna was found necessary in order to put the minimum SWR at 1812 kHz. In general, a 1-foot (0.31 m) change in height of the antenna changes the 80-meter resonance by 60 kHz and the 160-meter resonance by 15 kHz. A change of 1/2 turn on the



Bottom view of the matching network for the dual-band 80- and 160-meter vertical. The loading coil is on the right and the trifilar 4:1 and 9:1 matching transformer on the left. The dpdt 24-volt antenna relay switches in or out the loading coil and changes the taps on the transformer to the appropriate ratio. The enclosure is the conventional 4 X 5 X 6-inch (102 mm X 127 mm X 152 mm) aluminum Minibox.



The broadband bifilar transformer shown has 12 bifilar turns, no. 14 wire, on a ferrite (Q1 material, 2.5 inch [64 mm] OD) core. Taps are also placed at 3, 6, and 9 turns, thus yielding ratios of 1.5:1, 2:1, 3:1 and 4:1. This transformer has a connection at the 1.5:1 ratio tap. Extra insulation was provided for the enameled wire in order to prevent voltage breakdown when matching into loads greater than 50 ohms.

powdered-iron core coil changes the 160-meter resonance by about 50 kHz. It should be noted that the windings had extra insulation (about one layer of vinyl tape) added on the inside part of the windings in order to prevent breakdown between them.

Low-permeability ferrite material Q2 (μ = 40, but still four times larger than the powdered iron material) was also investigated for use as a core for a 160-meter loading inductance. It was hoped that with several stacked cores of this material, the flux density would be reduced to a level where nonlinearities and permanent damage could be avoided. Two cores and about 10 turns of wire were used. The result was negative. Large changes in inductance were noted on voice peaks by the sudden large changes in the SWR. Also, small but permanent changes in the SWR were observed, indicating permanent damage. In contrast to ferrite, powdered iron maintains its linearity at high flux densities and suffers no permanent damage. As noted above, four cores of permeability 10, and 22-1/2 turns, provided the proper inductance (approx. 30 μH). The loss in this coil was about equal to the air-wound coil (33 turns, 6 tpi, no. 12 wire, 2-1/2-inch [64 mm] OD). Two stacked powdered-iron cores of permeability 25 were also investigated. This arrangement required about 17 turns, but was rejected because the loss, which was mainly in the two cores, went up to 3 ohms. This is certainly intolerable since it is of the order of magnitude of the radiation resistance of the very short vertical.

Concluding Remarks

The predominant characteristic of the short antenna is probably its very low value of radiation resistance. One must be careful of excessive ground and ohmic losses in coils and matching networks. A good image plane can eliminate the ground-loss factor. The application of a top hat eases the problem somewhat because it increases the effective length and thus the radiation resistance. The radiation resistance can be increased five-fold[8] by resorting to complete top-hat loading of a vertical. Combinations of top-hat and inductive loading can be used depending upon the radiator height and the bandwidth desired. One can also resort to a short folded unipole. With these combinations at his disposal, the designer is left with the problem of efficiently matching his transmission line to various impedance levels. The wide-band transmission-line transformer can provide the answer. It is capable of operating very efficiently over a wide range of impedances and impedance ratios.

The author would like to acknowledge the generosity of the following companies who supplied cores and information for the experiments: Indiana General Corp., Amidon Associates, and the Arnold Engineering Co.

Finally, the author would like to thank his colleague Mort Fagen, WA2EIT, for his encouragement and discussions of the antenna papers the author has written. This material was originally presented in *QST* by Jerry Sevick, W2FMI.

References

[1] King, *The Theory of Linear Antennas,* Harvard University Press, Cambridge, MA, 1956.

[2] Sevick, "The W2FMI Ground-Mounted Short Vertical," *QST,* March 1973. (See chapter 1.)

[3] Ruthroff, "Some Broad-Band Transformers," *Proc. IRE,* Vol. 47, p. 137, August 1959.

[4] Turrin, "Application of Broadband Balun Transformers," *QST,* April 1969.

[5] Krauss and Allen, "Designing Toroidal Transformers to Optimize Wideband Performance," *Electronics,* August 16, 1973.

[6] Indiana General Corp., Electronics Div., Keasby, NJ 08832.

[7] Amidon Associates, 12033 Otsego Street, North Hollywood, CA 91607; The Arnold Engineering Co., Marengo, IL.

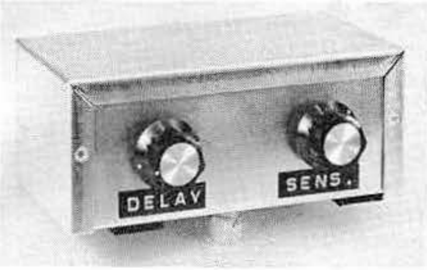
[8] See reference 2.

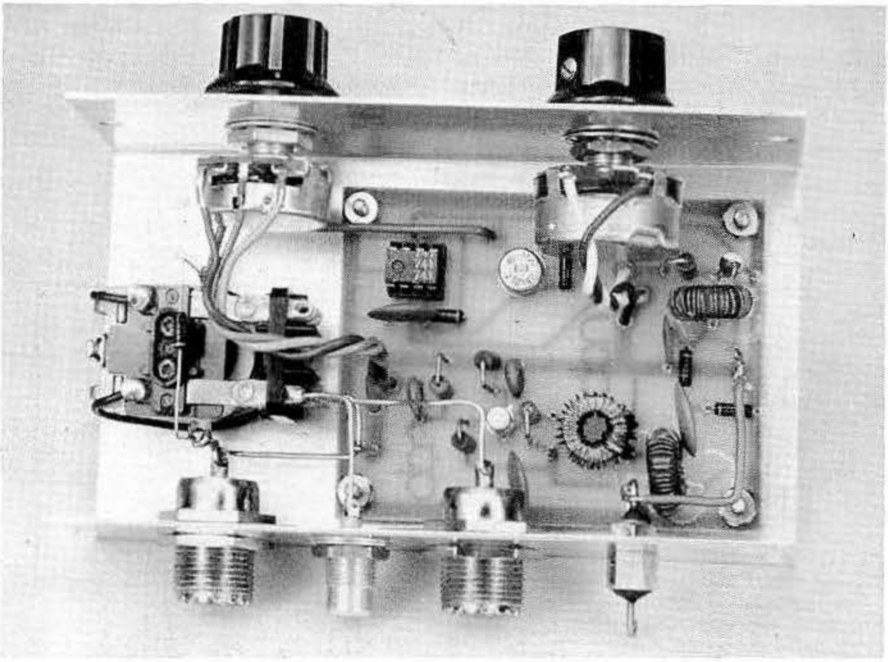
An RF-Sensed Antenna Changeover Relay

Flick of the switch, sir? Not with this system — it's automatic!

One subject that can be confusing for the newcomer to Amateur Radio is that of antenna-changeover systems. Several systems have been devised over the years and most can be classified into three or four main categories. Before delving into a discussion on these systems, a brief look at the simplest method of all might be in order, that is, no antenna changeover at all. With this setup two separate antennas are used, one for the transmitter and one for the receiver. This system is impractical for the most part since duplicate antennas would be required for each band of operation. There are instances, however, when separate antennas with different directive patterns can be used to an advantage, as in the case of specialized receiving antennas. Generally speaking, most stations use the same antenna for transmit and receiver purposes, so this is more the exception than the rule.

Several antenna-changeover systems, designed to transfer a single antenna from the receiver to the transmitter, are shown in Fig. 54. At A, a manual switch is used to transfer the antenna connection. This scheme is simple and works well, but is not without several drawbacks. Good-quality, high-power rf switches are often costly and





The inner layout of the antenna-changeover relay. Wiring or placement of circuit board and other components is not critical.

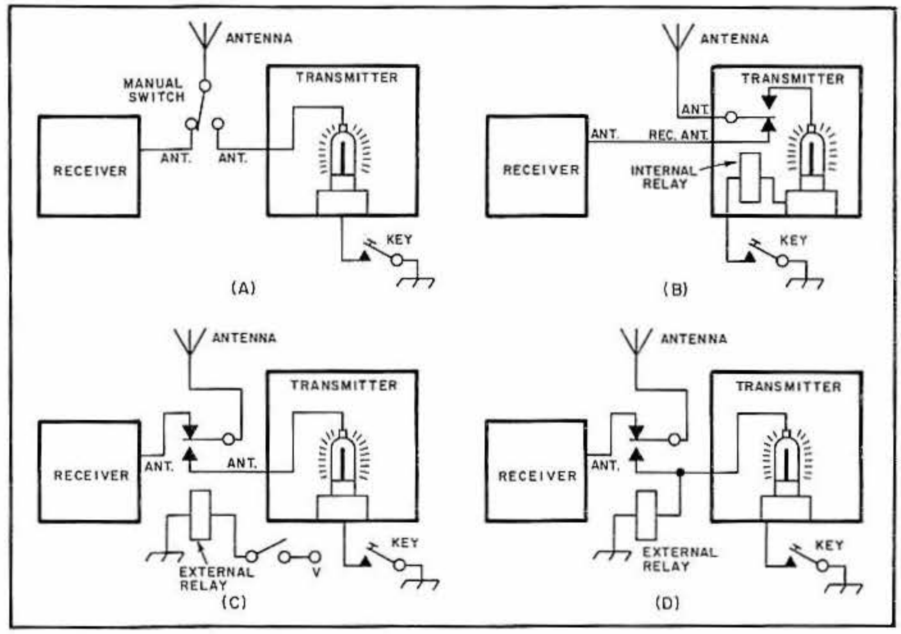


Fig. 54 — Several different antenna-changeover systems in block diagram form.

hard to locate and, of course, the operator is required to switch manually from receive to transmit.

One of these problems was eliminated with the advent of the coaxial relay. These relays were, in most cases, mounted external to the transmitter and receiver with connecting cables running to and from the unit, as shown in Fig. 54B. Many of these relays were rated for a kilowatt a-m signal, and maintained the 50-ohm line impedance. The voltage needed for the relay field was switched on or off with a low-powered toggle or foot switch. Alternatively, the transmit-receive switch might be located on the front panel of the transmitter with control voltage or a normally open or closed circuit available at a socket on the rear apron. Several extra sets of relay contacts were usually furnished with the relay to perform various functions, including that of muting the station receiver during transmit periods. Although this system of antenna transfer represented an improvement over the previous setup, it was still necessary for the operator to switch the antenna manually via the relay-control switch.

It's been said that laziness is the mother of invention and so it seemed natural that a more automatic system be developed. The relatively modern scheme at Fig. 54C has the transfer relay built into the transmitter. This system is quite popular and is used by most commercial manufacturers of amateur equipment that offer a separate transmitter and receiver. When the key is pressed the relay activates automatically and switches the antenna to the transmitter. A variable-length delay is usually included to hold the relay closed, thereby keeping the antenna connected to the transmitter during code characters. After the last group of code characters is sent, the relay will remain closed for a second or two — the amount of time controllable. When the relay deactivates, the antenna is reconnected to the receiver.

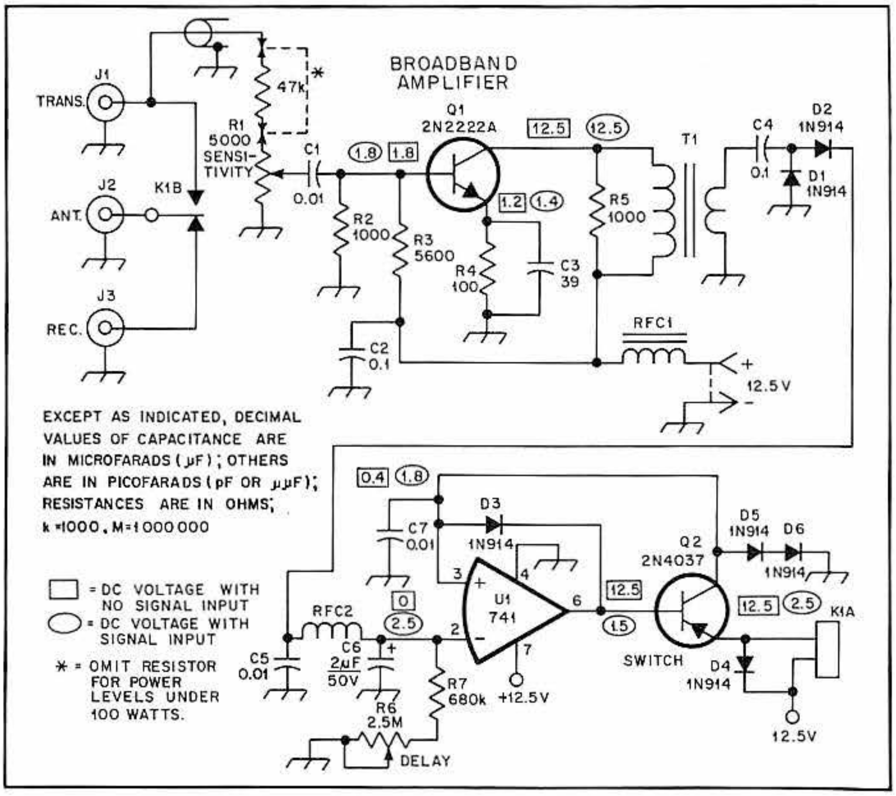
Unfortunately, some amateurs who build their own equipment or purchase transmitters and receivers of different manufacture, sometimes resort to switching methods A or B. These setups, of course, do not include the automatic features of system C. The circuit described here and shown in simplified form in Fig. 54D was designed with this in mind. Basically, this system detects the presence of rf at the output of the transmitter and immediately breaks the antenna connection to the receiver. At the same time the antenna connection to the transmitter is made. One of the features of this system is that no modifications to either the transmitter or receiver are required.

Circuit Description

R1 of Fig. 55 serves as an rf-voltage divider to permit the circuit to be used with transmitters of various power-output amounts. Rf energy is routed through C1 to the base of broadband amplifier Q1. The amplified hf-band energy is supplied to a voltage-doubler (D1 and D2) through a broadband toroidal step-down transformer, T1. The rectified rf voltage at the output of D1 and D2 is filtered by means of RFC2, C5 and C6. This prevents unwanted rf from reaching U1 and affecting its performance.

C6, R7 and R6 comprise a timing network (variable) which governs the hold-in time of the relay, K1. The smaller the resistance amount at R6, the shorter will be the time delay.

U1 functions as an inverting amplifier. When the input dc voltage at pin 2 increases, the output dc voltage at pin 6 decreases. The output voltage causes the base of relay driver Q2 to be forward biased negatively when it drops below approximately 1.4 volts. Diodes D5 and D6, by virtue of their combined barrier voltages (0.7 V each), establish the 1.4-V fixed bias level. Without the diodes, Q2 would conduct sufficiently to prevent the relay from dropping out during no-signal periods. D4 is used to suppress transients caused by the field coil of K1. When no rectified rf reaches U1, Q2 is cut off because of the high positive base voltage it receives from U1, and the relay contacts to the transmitter are open.



EXCEPT AS INDICATED, DECIMAL VALUES OF CAPACITANCE ARE IN MICROFARADS (μF); OTHERS ARE IN PICOFARADS (pF OR μμF); RESISTANCES ARE IN OHMS; k=1000, M=1 000 000

☐ = DC VOLTAGE WITH NO SIGNAL INPUT

○ = DC VOLTAGE WITH SIGNAL INPUT

* = OMIT RESISTOR FOR POWER LEVELS UNDER 100 WATTS.

Fig. 55 — Schematic diagram of the rf-sensed antenna-changeover relay. All resistors are half-watt composition type. Capacitors are disk-ceramic unless noted otherwise. Component numbers not appearing in the parts list are for identification purposes only.

J1, J2 — Connector, SO-239.
J3 — Connector, phono-type.
K1 — Dpdt relay, 5-ampere contacts, 12-volt field.
R1 — Linear potentiometer, 5000 ohms.
R2 — Linear potentiometer, 2.5 megohms.
RFC1, RFC2 — Rf choke, 42 turns no. 28 enam. wire on an Amidon FT-50-43 core.
T1 — Broadband transformer. Primary: 25 turns no. 28 enam. wire on an Amidon FT-50-43 core; secondary: 5 turns no. 28 enam. wire wound over primary winding.
U1 — Op amp, 741.

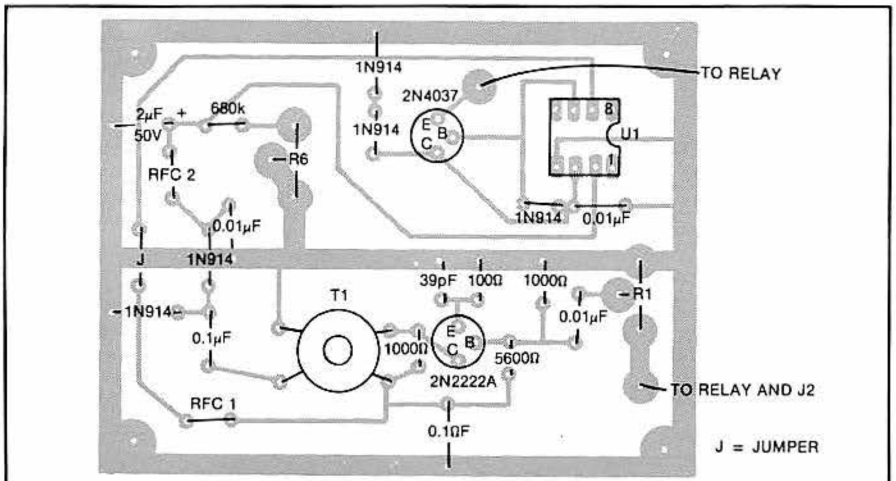


Fig. 56 — Circuit-board etching pattern for the changeover relay. The pattern is shown at actual size from the foil side of the board with gray areas representing copper. Decimal-value numbers alone represent capacitance in microfarads. Whole-number values with no units represent resistances in ohms; k = 1000. J = wire jumper. All components are mounted on the nonfoil side of the board. K indicates the cathode of a diode.

Construction

In Fig. 56 is a suggested printed-circuit board layout showing the foil pattern and parts placement. R1 and R6 may be circuit-board-mounted potentiometers if the builder desires, as the board layout was designed to accommodate such units. Potentiometers of this type are entirely suitable if the builder does not anticipate frequent changes in power levels and length of delay, as these controls must be readjusted for such changes. If the builder is interested in having access to these controls, panel-mounted potentiometers can be used at the front apron, in which case wires will have to be run from the circuit board to the controls.

Our finished model was housed in a 5 × 3 × 2-inch (127 mm × 76 mm × 51 mm) aluminum Minibox. R1 and R6 were mounted on the front panel and Kurz-Kasch knobs were placed on the control shafts to dress up the appearance of the finished product. D4 is attached directly to the relay terminals. The rear panel supports the terminals for the transmitter, antenna, receiver antenna and power supply. SO-239 connectors were used for the transmitter and antenna connections, and a phono connector was employed for the receiver antenna. Any type of connectors may be substituted to match those used in the builder's station. The power-supply lead is brought out through a feedthrough capacitor. This type of feedthrough is not necessary; a simple feedthrough insulator or wire could be used instead. In our case, the capacitor lead served as a convenient tie point during preliminary testing of the unit.

Operation

Connect the antenna, transmitter, receiver antenna lead and the power-supply connections to the appropriate terminals. Set R6, the time-delay control, to its minimum delay position (ccw) and the sensitivity control to its midrotation position. While keying the transmitter, decrease the setting of the sensitivity control to a point just above that where the transmitter no longer makes the relay energize. Once this has been set, it may be left in that position until a moderate change in power level has been made. The delay control should then be adjusted for the length of delay desired. The circuit shown has been tested from 1.8 to 30 MHz and at dc power input levels up to and including 1000 watts. This material was originally presented in *QST* by Doug DeMaw, W1FB, and Jay Rusgrove, W1VD.

Measuring Antenna Gain with Amateur Methods

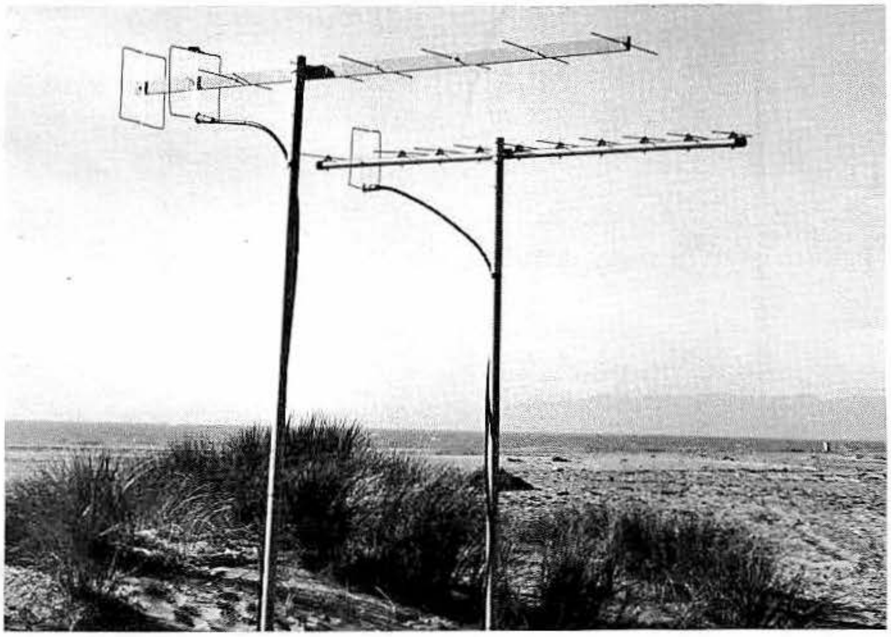
Beat the cost of expensive test gear. Make your antenna measurements using this unique method! A VU meter, a handful of parts and this simple explanation are all you need.

Several excellent articles have been written about the techniques used at vhf conferences to measure antenna gains. Two such articles in particular, by Clark[1] and Knadle,[2] suggest very good antenna-range procedures. Both describe techniques which, if properly applied, will produce accurate relative antenna-gain data (in decibels) for vhf-uhf antennas.

However, these antenna range-measurement systems require equipment most amateurs lack — ratiometers, precisely calibrated attenuators, or at least specialized detectors and commercial grade audio or VSWR meters. Moreover, setting up a near-field antenna range is a tricky business in itself. One text[3] simply warns amateurs not to expect accurate antenna-gain measurements if they try it! The problem, of course, is that outdoor antenna ranges invite all sorts of error-causing reflections from various objects, not the least of them being the earth itself.

Ground reflections alone can completely invalidate the results on an otherwise good antenna range. At the 1973 West Coast VHF Conference, for instance, the author's 8-element quagi for 432 MHz[4] was measured at precisely the same gain as a well-built 15-element Yagi more than twice its size, despite the fact (established in other tests) that the bigger antenna had 2 to 3 dB more actual gain! The problem was that, even with the sophisticated measuring equipment in use, ground reflections were distorting the results. The best "gain" indication came with both antennas within a few inches of the earth, and the smaller quagi with its lower Q didn't mind the detuning effects of the earth's proximity as much as the bigger and higher Q array.

With results like that, wild claims are sometimes made for one vhf antenna or another. And the claims may be even wilder on the hf bands, where an amateur may well be told his signal is two of three S units louder than another ham's signal when the actual gain difference between the two antennas is insignificant. The ham who "won " the comparison by several S units, of course, is likely to go away thinking his antenna is 12 or 18 dB better than the other guy's, since S meters are supposed to show 6-dB signal difference per S point.



For the antenna gain-measurement technique described here, two identical masts in a clear area (here a southern California beach) are required. With the test and reference antennas at equal heights and fed with identical feed lines, the signal produced by the two antennas is compared by rapid and repeated switching. Here an 8-element quagi is tested against an 11-element Yagi that has been modified for quagi-type drive. The modified Yagi delivers 3 dB more gain than the conventional version, but 2 dB less than the quagi.

A Better Way

This article describes a more reliable and valid way to estimate antenna gain, and without expensive or hard-to-find test equipment. The technique requires only this equipment: a cooperative nearby ham with a transmitter capable of generating a few watts of steady carrier, a receiver whose agc can be turned off, an ordinary audio VU meter, and some antennas to measure.

The technique is nothing more than a more rigorous application of the test procedure radio amateurs have always used when they asked for "comparison" signal reports. It takes advantage of the fact that audio VU meters, unlike S meters, are calibrated directly and fairly accurately in decibels, with easy readout down to fractions of a dB. And with the agc turned off, most receivers will closely reproduce changes in the signal input at the antenna terminals with corresponding changes in audio output until they are badly overloaded.

This means that a nearby amateur's signal transmitted at a reasonably low power level can be used to compare the gain of various antennas by rapidly switching back and forth between them and averaging the results.

The only trick is to use a "test signal" that is coming from a point source — not a signal that is being reflected from surrounding objects. If your test antennas can "see" the signal source a few miles away and are well clear of nearby objects (and clear of the earth itself), valid results should be attainable if the procedures below are followed.

The author has spent many hours working with both local antenna ranges covering a few dozen wavelengths, and on-the-air signals from local stations. It is apparent that ground reflections and other

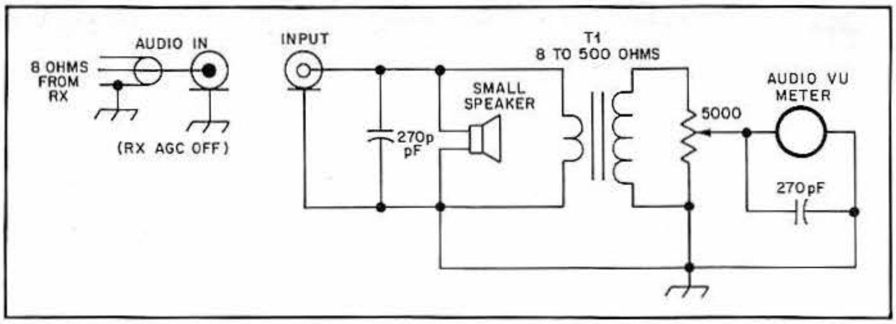


Fig. 57 — The audio VU-meter system for antenna gain measurements.

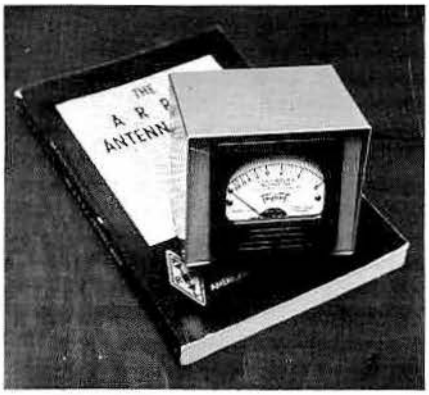


Fig. 58 — This small box houses all the test equipment required for antenna gain measurements using the technique described here. The front-panel audio VU meter is calibrated directly in decibels, with readout possible to about 0.2 dB in the most expanded part of the scale. Not visible are the meter level potentiometer (on rear), and small speaker which is mounted downward.

such error sources are less serious problems when a steady, on-the-air carrier a few miles away — and not a local signal a few dozen wavelengths away — is the signal source.

Test Procedures

Here's how the procedure works at vhf (at hf, it's a little more complicated because antennas are larger, as we'll see later):

1) Build an audio VU metering circuit like the one shown in the photo and Fig. 57. All parts should be readily available anywhere that consumer electronics parts are sold. The speaker and meter-gain control are handy to have when the receiver itself is located some distance away from the antenna test site, but they aren't absolutely essential.

2) Get a nearby amateur (perhaps one to five miles away) to generate a steady carrier into an antenna of the same polarization as your test antennas. A small beam pointed toward your test site is much better than a dipole or groundplane antenna because it is less likely to invite reflection error. A beam pointed somewhere else is worst of all!

3) Two of the antennas to be tested should be set up side by side, with identical lengths of feed line going to a coaxial relay or well-isolated switch. The two supporting poles should be high enough that the test antennas are at least two wavelengths above ground (13 feet [3.96 m] or more at 2 meters) and clear of nearby obstructions. To minimize interaction between the two antennas, the two masts should also be at least one to two wavelengths apart and standing side by side in relation to the signal source.

4) Make sure you can raise and lower your antennas and move them from side to side by at least a full wavelength or so (81 inches [2.06 m] at 2 meters) without the indicated signal varying more than about 1 dB. If you can't do that, you probably have reflection problems that will have to be solved before you can make valid readings. If this is the case, try different sites until you do achieve nonspotty reception.

5) Check the receiver agc to be sure it is off; then rapidly switch between the two antennas and record the difference in decibels. Do it several times and calculate the average figure (the mean, for statisticians).

6) Next reverse the two antennas. Put antenna no. 1 on mast no. 2 and attach it to feed line no. 2. Move antenna no. 2 over to mast no. 1 and feed line no. 1. Do not eliminate this step and expect valid results.

Now run the test again. If there are more than very slight differences from the previous test, one antenna or the other is seeing some obstruction or reflection source. Your site isn't clear enough for good results; try a different one.

Since this test procedure requires only receiving, there is no reason not to perform it somewhere other than at home — anywhere that is clear of obstructions. Use a receiver or transceiver that runs on battery power, if necessary.

7) If you have followed steps one through six, you now have an accurate indication of the relative gain of your two antennas. Now you can make one of your antennas a "reference" antenna and compare any other antennas you or

Fig. 59 — Here a 15-element long-boom quagi for 432 MHz is compared to a 16-element log-periodic Yagi, using the test procedure described in this article. The two antennas both deliver 15 dB gain over a dipole, decisively better than any other 432-MHz antenna tested here. The antennas to be tested are set up side by side and fed with identical lengths of coax. The antennas should be at least two wavelengths above ground and clear of nearby obstructions. To minimize interaction between the two antennas, the masts should also be at least one to two wavelengths apart, and standing side by side in relation to the signal source.

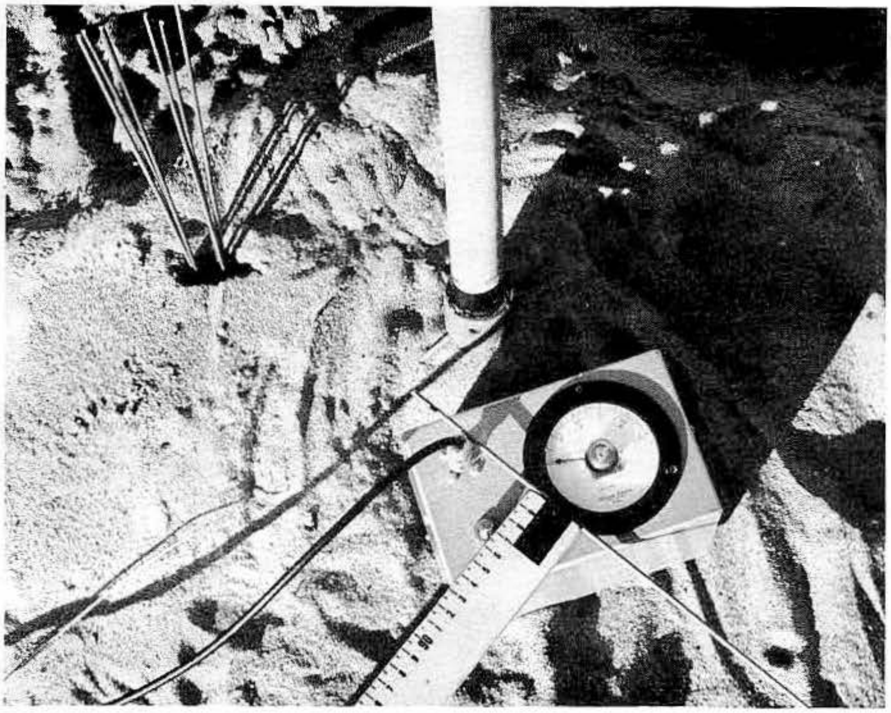


Fig. 60 — An earlier version of the metering system in Fig. 57, with assorted elements of various lengths and the yardstick used to make temporary placements on the boom.

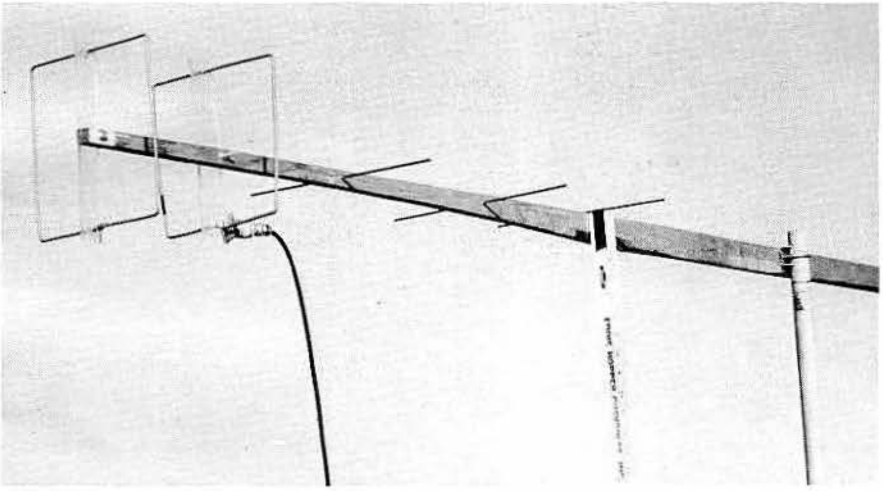


Fig. 61 — The technique used to design a new vhf or uhf antenna experimentally. The boom is shown with the first few elements already in place, and each additional element is adjusted back and forth on the boom until a point of maximum indication of the VU meter is found.

neighboring hams have against this reference.

So how do you determine how much gain your antennas have over a dipole? Some people would say, "Simple, make the reference antenna a dipole." But it may not be that easy, because dipoles are notorious for finding reflections that more directional antennas can't "see." At vhf conference gain-measurement seminars, dipoles have sometimes shown as much as 3 or 4 dB gain over a dipole!

The best reference antenna is probably a small beam of known (or approximately known) gain, assuming you don't have the National Bureau of Standards type of reference antenna that professionals use for this purpose. A 3-element Yagi or a 2-element quad built to handbook dimensions will usually deliver about 6 dB gain over a dipole at 2 meters, if the SWR is okay at the design frequency.

Thus, if you find that a particular 8-element antenna consistently produces 4.5 more dB on the VU meter than your little reference beam, you'll know you have an antenna with about 10.5 dB gain. You won't be exactly correct, but you'll be close to the right figure. Conversely, if your bigger beam doesn't show much gain over the small one, and there are no measurement errors of the sort just described, you'll know for sure that something is wrong with the big antenna.

Once you have established the integrity of your test site, you can even design your own antennas very accurately, using the audio VU-meter technique. To do that, set up your reference antenna and begin designing your new antenna by putting an empty boom on the other pole. Now start with 2 or 3 elements, get a decent SWR and try adding more elements.

As you add elements, you will be able to actually see where each new element "wants to be" on the boom, and you can see your new antenna gain over the reference antenna increase as you go along. Try all sorts of element lengths and spacings as you progress.

Antenna design professionals call this process "perturbation" and they do it with sophisticated mathematics, but you can design antennas that work just as well as theirs on your own antenna range, once you master this technique. Then, if you do go to a vhf conference with your best home-designed antennas, you'll know about how much gain they have before you enter the gain contest. And you'll never come away from such an event with an antenna that has "minus 3 dB gain!" Moreover, you'll know that your measurements, made without any of the sophisticated equipment you saw at the vhf conference, are about as accurate as anybody's. In fact, you may find your own measurements are more valid than the ones at the conference, especially if the antenna-gain figure jumps all over the place when you raise and lower it at the conference antenna range.

HF Antenna Measurements

So far, all of this has been devoted to vhf antenna-gain measurements. Many readers will say, "That's fine, but I want to measure the gain of my 5-element 20-meter beam!" Of course, an audio VU meter and a receiver without agc are a much better way than the notoriously inaccurate S meter to compare two dissimilar hf antennas. The author has seen an S meter show three or four *S units* of signal difference between two antennas that are really only 3 or 4 dB apart in gain.

However, the only accurate way to calculate the gain of an antenna is to compare it to a reference antenna at the same height and then switch the two antennas to opposite masts to validate the data. That may be impractical at hf, but perhaps not as much so as it seems at first. Most amateurs motivated enough to install a 5-element beam on a crankup tower can probably find a way to temporarily set up a smaller beam (not a dipole) on a 20-foot (6.10 m) mast above a roof. Then the two antennas at identical heights can be compared on stable, line-of-sight signals.

The results of this test can be invalidated by obstructions or even by other antennas mounted on the same tower with the test antenna, but at least this will be more valid than a comparison against another ham's readings, when the two locations and rigs may be entirely different.

And if you can switch your test reference hf antennas to opposite masts, you can measure the actual gain of one over the other. One suggestion before you put that giant, long-boom array on the big tower: Put a little beam on the tower and an identical one on the rooftop mast and perform the audio VU-meter tests to see if the two antenna sites do seem to be identical. If they are comparable, then you can put the big antenna on the tower and find out how much gain it has, if any, over the small one on your roof when the two are at the same height.

This may seem cumbersome, and in fact it is! That's why most antenna designers do their research at vhf where antennas are so nice and small, and then scale their best designs up for the hf bands. But if you really want to know your big beam's actual gain, this is probably the easiest way to find out.

Conclusions

The antenna gain-measuring technique described in this article has repeatedly been proved to be reliable and valid. The author has used it to design new antennas that work well enough for all kinds of contest and DX work, including moonbounce. For a dedicated amateur, working DX on a home-designed antenna far surpasses the thrill of working the same DX with an antenna purchased at a store! But remember, whether you're working 20 meters or 23 centimeters, a signal source, a receiver with its agc disabled and an audio VU meter are the only pieces of equipment you need to measure antenna gain with this technique. This material was originally presented in *QST* by Wayne Overbeck, PhD, N6NB.

References

[1] Clark, "Direct Methods for Measuring Antenna Gain," *Ham Radio,* July 1969.
[2] Knadle, "UHF Antenna Ratiometry: An Outdoor Range Improvement Technique," a paper presented to IEEE Intercon session L, April 1975.
[3] Brier and Orr, *VHF Handbook for Radio Amateurs,* Radio Publications, Inc., Wilton, CT p. 225.
[4] Overbeck, "The VHF Quagi," *QST,* April 1977.
[5] Knadle, "UHF Antenna Ratiometry," *QST,* February 1976.

Index

"Airstream Loop," 75-meter: 90
Antenna ideas: 93, 109
Apartment dweller's dilemma: 92
Aperture: 54

Baby ultimate Transmatch: 138
Balun: 136
Base loading network, vertical: 17
Beams: 41, 53
Bobtail array: 81
Bridge, resistive antenna: 131
Bridge, SWR: 125
Broadband matching networks, simple: 140
Broadband matching transformers: 140

Capacitance hats: 111
Capacitive loading: 110
Capacitor-tuned quad: 63
Changeover relay, rf-sensed: 142
Coil housing box: 10
Comparisons:
  High vs. low antennas: 102
  Quad vs. Yagi: 53, 100
Computer-modeled arrays and patterns: 119
Coupling methods: 104
Cross-modulation, receiver: 135

DDRR, 40-meter: 95
Delta-Loop beam, HRH: 84
Delta Loop, 10-meter: 84
Delta Loop, 15-meter: 86
Delta Loop, 20-meter: 85
Dipoles: 89
Dipole, off-center-loaded: 107
Directive arrays: 41, 53
Directivity: 53
Director spacing, effects of: 50
Distributed loading: 26
Dual-band 160- and 80-meter vertical: 141
DX antenna, 160- and 80-meter: 34
DX weasel, 20-meter: 41

Efficient short radiators: 13, 25, 27, 112, 141
E-skip tests, 6-meter: 103
Etched-circuit Monimatch: 123

Ferrite-rod loop: 78
Folded mini quad: 69

Gain, measuring with amateur methods: 145
Gain, quad vs. Yagi: 55
Ground-image vertical: 22
Grounding systems, verticals: 29
Ground-mounted short verticals: 25
Groundplane, H-plane pattern: 11
Groundplane with tuned feeders, multiband: 19
Ground-wave tests: 103

Half-size 80-meter: 110
Half square array, three-element: 82
Half square array, two-element: 82
Half square, 80-meter: 81
Harmonic problems: 33, 135
Helical, 8-1/2 ft: 26
Helically wound vertical, 75-meter: 20
Hf measurements: 147
High vs. low antennas: 102
Horizontal vs. vertical: 32
H-plane pattern, groundplane: 11
HW-40 micro beam: 43

Impedance properties and matching, quad: 56
Inductive loading: 110
In-line rf power metering: 126
Input resistance vs. number of radials: 27

L-network Transmatch: 92
Loaded antennas for travel: 89
Limited-space antennas: 7, 104
Linear array, vertical four-element: 118
Loading coils with multiband antennas: 112
Loading, capacitive and inductive: 110
Loading, distributed: 26
Loading, top-hat: 26
Loads, antenna: 133
Loads, transmitter: 104
Load, 50-ohm: 123, 135
Log-Yag array: 49
Loop:
  Antenna, W1FB 4T-ES: 80
  Antennas for receiving: 76
  Experiments: 78
  Ferrite-rod: 78
  Four-turn coax: 80
  Four-turn shielded: 77
  Indoor: 77
  40-meter full wave: 98
  160-meter indoor receiving: 80

Matching networks, simple broadband: 140
Matching, two-band quad: 75
Measuring gain with amateur methods: 145
Metering, in-line rf power: 126
Micro beam, HW-40: 43
Minooka special: 36
Minooka special, mobile: 38
Miscellaneous antenna types: 76
Monimatch, etched-circuit: 123
Monopole, 40-meter: 90
Multiband antennas: 7, 9, 11, 13, 16, 18, 19, 32, 45, 60, 92, 133
Multiband antennas with loading coils: 112
Multiband ground plane with tuned feeders: 19
Multiband verticals: 16, 32
Multiband verticals, nontrap: 33

Noise, beating: 76
Novice four-band vertical: 9
Novice two-band vertical: 7
Novi-Loop: 98

Off-center-loaded dipole: 107
Optimizing verticals: 29, 115

Phased array, dissimilar antennas: 30
Pi-network tank circuits: 132
Polarization, quads: 54
Portable 160-meter vertical: 38
Power dividers, rf: 120
Preamplifier, broadband 40-dB: 78

Quads: 53
  C-T, reduced size: 63
  Folded mini: 69
  Impedance properties and matching: 56
  Matching, two-band: 75
  Polarization: 54
  Radiation angle: 54
  Spider mount: 74
  Stub tuning: 70
  Triband one-loop cubical: 60
  Yagi-type directors: 74
  7-MHz, linear-loaded: 73
  15-meter, two-element: 61
  40-meter: 62
  80-meter two-element: 66
Quad vs Yagi: 53, 100

Radials, input resistance vs. number of: 27
Radiation angle, quad: 54
Radiation resistance/height curve: 27
Random-length wires: 92, 104
Reactance compensation: 18
Receiver cross-modulation: 135
Resistive antenna bridge: 131
Rf power dividers: 120
Rf power metering, in-line: 126
Rf-sensed changeover relay: 142
Rod-loop tests: 79
Rod loop, sense antenna with: 79

Scoop loop beats noise: 76
Sense antenna: 79
Short radiators, efficient: 27, 112
Short vertical design: 13, 25, 27, 141
Short verticals, SWR: 28
Shunt-feeding towers: 34,
Simple arrays of vertical elements: 114
Spider quad mount: 74
Square array, vertical four-element: 118
Stub tuning, quads: 70
SWR: 124
SWR bridge: 125

Tank circuits, pi-network: 132
Theory and test methods: 100
Top hat loading: 26
Towers, shunt-feeding: 34
Transformers, broadband matching: 140
Transmatch: 92, 105, 132, 135, 138
Transmatch, baby: 138

Transmatch, L-network: 92
Transmatch, Ultimate: 135
Transmission lines: 124
Transmitter loads: 104
Trap antennas: 33, 133
Trap verticals: 33
Travel trailers and campers: 89
Triangle three-element vertical array: 122
Tribanders: 13, 18, 60, 100
Triband one-loop cubical quad: 60

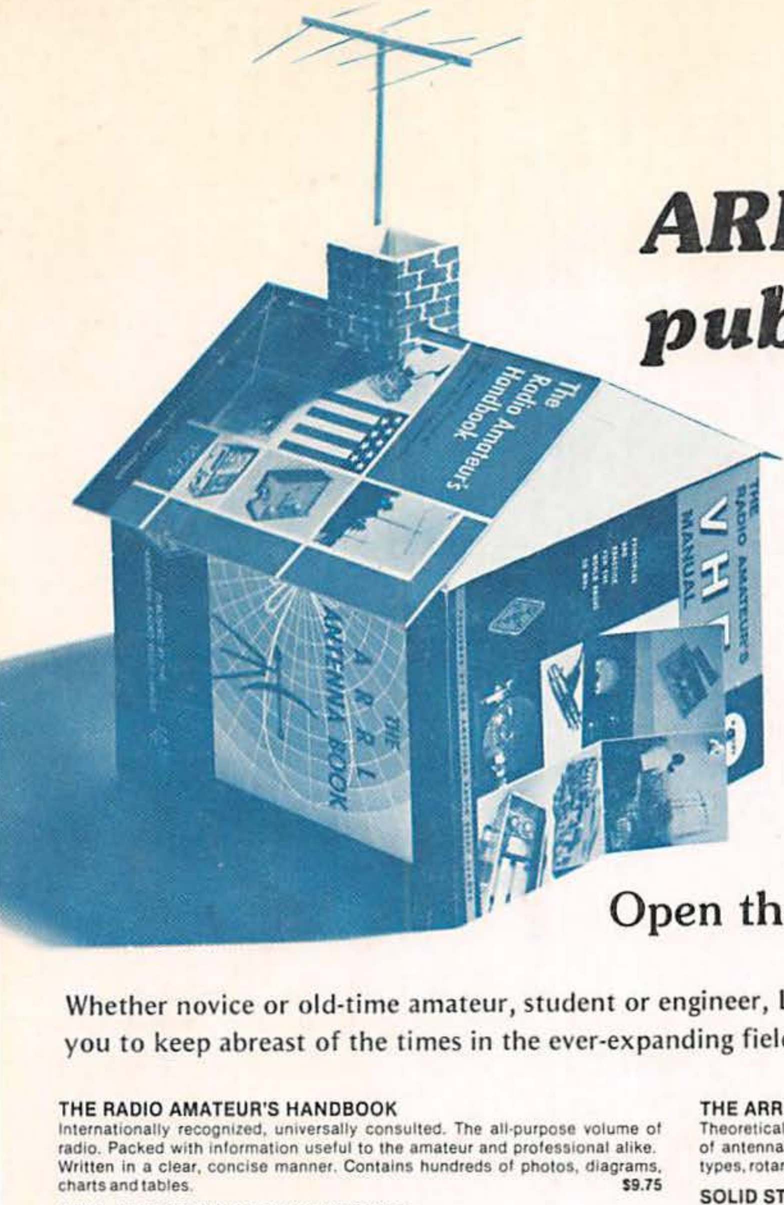
Ultimate Transmatch: 135
Ultimate transmatch, baby: 138

Varimatcher: 105
Verticals: 7
  Four-element arrays: 117
  Ground-image: 22
  Ground-mounted short: 25
  High-performance 20-, 40- and 80-meter: 13
  Linear array, four-element: 118
  Multiband: 32
  Multiband groundplane with tuned feeders: 19
  Nontrap multiband: 33
  Novice four-band: 9
  Novice two-band: 7
  Optimizing: 29, 115
  Radiator, multiband: 16
  Short design: 13, 25, 27, 141
  Simple arrays: 114
  Square array, four-element: 118
  Three-element arrays: 117
  Trap: 33
  Triangle three-element array: 122
  Types of: 32
  Two-element array: 115
  5/8-wave, 20-meter: 39
  10- and 15-meter groundplane: 11
  10-, 15- and 20-meter: 18
  75-meter, helically wound: 20
  160-meter: 36
  160- and 80-meter system: 141
  360-degree steerable phased arrays: 119
Vertical vs. horizontal: 31

Why a Transmatch?: 132
Wilkinson power dividers: 121
Wire, nonresonant, random-length: 92

Yagis: 41
  Director spacing, effects of: 50
  Helically wound, two-element, 40-meter: 43
  Log-Yag array: 49
  20- and 15-meter bite-size beam: 45
  20-meter DX Weasel: 41
  20-meter minibeam: 48
Yagi-type directors for quads: 74
Yagi vs. quad: 53, 100

6-meter E-skip tests: 103
7-MHz, linear-loaded quad: 73
10- and 15-meter groundplane: 11
10-meter Delta Loop: 84
10-, 15- and 20-meter one-loop quad: 60
10-, 15- and 20-meter vertical: 18
15-meter Delta Loop: 86
15-meter quad, two-element: 61
20- and 15-meter bite-size beam: 45
20-meter arrays, beam patterns: 50
20-meter beam, linear loaded: 48
20-meter Delta Loop: 85
20-meter DX Weasel: 41
20-meter minibeam: 48
20-meter, 5/8-wave vertical: 39
20-, 40- and 80-meter vertical system: 13
40- and 15-meter vertical: 7
40-meter DDRR: 94
40-meter full-wave loop: 98
40-meter monopole: 90
40-meter quad: 62
40-meter vertical, short: 25
40-meter Yagi, helically wound two-element: 43
50-ohm load: 123, 135
75-meter "Airstream Loop"' 91
75-meter, helically wound vertical: 20
80-meter DX antenna: 34
80-meter, half-size: 110
80-meter half-square: 81
80-meter quad, two-element: 66
80-meter receiving loop: 76
80-meter vertical, short: 27
160-meter DX antenna: 34
160-meter indoor receiving loop: 80
160-meter, space-saving vertical: 40
160-meter vertical: 36
160-meter vertical, portable: 38
160-meters, receiving loop: 76
160- and 80-meter vertical: 141
160 on 80-meter half-square: 83
360-degree steerable vertical phased arrays: 119



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